LE PENSEUR.

(From the statue by Rodin: Bulloz, Photo.)

THE MASTER THINKERS

Vignettes in the History of Science

With Portraits

BY

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TO

MY GRANDSON

DAVID LAWRIE ROWATT

PREFACE

The following work does not profess to be in any sense a History of Science. It is merely a series of sketches of the lives and achievements of a few of the great discoverers of the facts and laws that together comprise what we know as Natural Science. Many names have been omitted, since exigencies of space forbade their insertion, and the enormous developments of the past fifty years have been left unnoticed for the same reason, as also because a treatment of these years would have involved a consideration of the accomplishments of men still alive and of theories that are still on trial or in the making. The sketches, therefore, terminate about the middle of last century.

The author desires to express his indebtedness to the publications of many writers and to articles, too numerous to mention, on specific subjects and persons scattered through encyclopædias or manuals of the different sciences.

He would record his very cordial thanks to his friends, Professor J. Joly, D Sc, F.R.S, Trinity College, Dublin, and especially to G. G. Chisholm, M A, LL D, Emeritus Reader in Geography, University of Edinburgh, who have most kindly read through the proofs of this work and favoured him with many suggestions of which he has taken full advantage

Should his hope be fulfilled of awakening or stimulating interest in the development of science in the minds of youth, his aim will have been achieved, and his reward will be their appreciation of his effort.

The appended list of a few of the works more frequently referred to and quoted may be of service to those who desire more detailed information. In these volumes references to other works will be found in abundance.

R J Harvey-Gibson

1928.

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INTRODUCTION

"I hope that my children at least, if not I myself, will see the day when ignorance of the primary laws and facts of science will be looked upon as a defect only second to ignorance of the primary laws of religion and morality."—CHARLES KINGSLEY.

IN prehistoric times science began with the unconscious observations of primitive man on the phenomena taking place around him. He could not help but notice that the sun rose and set each day, that the moon waxed and waned, that tides ebbed and flowed, and that the stars seemed to move in a vast hemisphere over his head. His efforts to improve the conditions of his existence taught him that the earth he inhabited consisted of various types of material, some solid, some liquid, some gaseous; that some of these materials might be solid under some conditions, and liquid or gaseous under others; that they varied in weight, in colour and consistence; that they might be useful to him or, so far as he could see, valueless, and that he could adapt many of them to his needs. He recognized that plants and animals were good for food, and that some of them could be cultivated, or tamed, for his service, and that many, especially plants, could be used to alleviate his ailments or heal his wounds In short, his crude observations laid the foundation of the sciences of Astronomy, Geology, Physics, Chemistry and Biology.

It was only to be expected that his first interpretations of natural phenomena should be anthropomorphic, that is to say, that he should see beings like himself, but vastly greater and more powerful, operating in every event that took place in his daily life, beings that had to be placated

when they appeared to injure him and prayed to when he desired their aid.

As time went on, men began to realize that this primitive way of looking at Nature did not satisfy their growing intelligence, and some of them began to formulate more rational explanations of natural phenomena. The first attempts at these interpretations, of which we have any record, were made by the philosophers that lived on the borders of the Eastern Mediterranean, several hundred years before our era. There is little doubt that long before the time of the Ionian thinkers considerable progress had been made in the elucidation of natural laws by the inhabitants of Mesopotamia and by those who dwelt in the fertile valley of the Nile, but our knowledge of their achievements is limited by the paucity of the records they have left behind them.

Then there came a time when the great intellectual activity of Greece was obscured and eclipsed in large measure by the utilitarianism of Rome, and science was lost in the darkness of the Middle Ages. But the seeds had been sown, and, although for more than a thousand years they lay dormant, the seedlings at length began to sprout, when the Revival of Learning took place about the eleventh century. The lost writings of the classical authors were rediscovered, the spirit of inquiry was reawakened, the world was being explored and the wonders that exploration revealed demanded interpretation. The mythological explanations that had satisfied the ancients did not bring conviction to the minds of the new race of inquirers. The gods of the lightning and the storm, of the woods and the mountains, faded away into misty abstractions as the dawn of reason began to appear, and, from that day till this, science has progressed with such leaps and bounds that now it is more than one man can accomplish to master even one branch of science, let alone all; many, indeed, have begun to recognize that they must rest satisfied with the cultivation of a section of one science only. Specialization has become essential if progress is to be made.

But, for the beginner, it is possible to obtain a glimpse of the evolution of science as a whole by tracing the history of discovery from its birth in the minds of the Greek philosophers, to its adolescence at least, though not to its maturity, in the twentieth century. That long period of over 2,500 years divides itself naturally into four chief epochs: first, the classical period, centring round the famous schools of learning at Athens and Alexandria; *second*, the period of the eclipse of science, when the flickering flame was kept alive by the Arabs; th[illegible] t texts and the dawn of mode[illegible] Bacon and Copernik boldly [illegible] beliefs [illegible]

[illegible] cumulative. What the years to come may hold in store we know not, but we may feel assured that just as a stone dropped from a height falls more and more rapidly from its point of departure until it reaches the earth, so science will advance with ever-increasing strides from year to year and from century to century.

> "True it is Nature hides
> Her treasures less and less. Man now presides
> In power, where once he trembled in his weakness;
> Science advances with gigantic strides

Yet must we not neglect Wordsworth's added caveat:

> "But are we aught enriched in love and meekness?"

THE MASTER THINKERS

CHAPTER I

THE ACADEMY AND THE LYCEUM

EIGHTEEN centuries ago or thereabout a tourist called Pausanias came over from Lydia in Asia Minor to explore the wonders of the land of Greece, and, like many another tourist, wrote an account of his travels, which he entitled *A Description or Itinerary of Greece.* In his book he shows himself primarily as an antiquary, recording everything he saw in short, pithy, unrhetorical sentences,

century of the Christian era.

He tells us his impressions on his arrival at Athens in the following words.

"The road to Athens is a pleasant one, running between cultivated fields the whole way. The city itself is dry and ill supplied with water. The streets are nothing but miserable old lanes, the houses mean, with a few better ones among them. On his first arrival a stranger could hardly believe that this is the Athens of which he has heard so much. Yet he will soon come to believe that it is Athens indeed. A music hall, the most beautiful in the world, a large and stately theatre, a costly, remarkable and far-seen temple of Athena called the Parthenon, rising above the theatre, strike the beholder with admiration. A temple of Olympian Zeus, unfinished, but planned on an astonishing scale; three gymnasiums, the Academy, Lyceum and Cynosarges, shaded with trees that spri--

from the greensward; verdant gardens of philosophers; amusements and recreations; many holidays and a constant succession of spectacles;—all these the visitor will find in Athens.

"Close to the city is the Academy, once the property of a private man, but in my time a gymnasium. On the way to it is an enclosure sacred to Artemis. . . . Before the entrance to the Academy is an Altar of Love. In the Academy is an Altar of Prometheus, and they run from it to the city with burning torches. Not far from the Academy is the tomb of Plato, to whom God foreshadowed his future greatness in philosophy." (Sir J. G. Frazer.)

The Academy was on the west side of the city and the Lyceum on the east, and, as the reconstructional maps show us, both were outside the city walls. Nowadays there is nothing left of these two famous academies. Gone are the halls and "gardens of the philosophers," where Plato taught his pupils the results of his own meditations, after the manner of his master, Socrates, by question and answer, as preserved for us in his Dialogues. Gone, too, is the Lyceum, close to the gardens dedicated to Apollo Lyceius, where Plato's greatest pupil, Aristotle, walked beneath the shade of the olives and myrtles and discoursed on Logic, Rhetoric, Physics, Metaphysics and Ethics to his students as they strolled after him—Peripatetics, as they were called—assuredly a much pleasanter environment in which to imbibe knowledge than the often dingy and not always over-clean lecture-rooms and laboratories of a modern university.

The Academy was founded by PLATO about 387 B.C., and was organized somewhat on the lines of a religious brotherhood or monastery. The founder was the head or master, and his assistants were his chosen pupils, a system not unlike that of an Oxford or Cambridge college. In his early life, after the death of his teacher, Socrates, he travelled much in Asia Minor, Egypt and Italy, and, no doubt, during his sojourn in these lands he became acquainted with the doctrines of Pythagoras, the mathematician; but his whole teaching in after life in the Academy appears to

have been theoretical and speculative rather than practical. "For him there were two worlds, the world of sense and the world of ideas. The senses deceive us; therefore the philosopher should turn his back upon the world of sensible impressions and develop the reason." Over the doorway

PLATO.

of the Academy, it is true, was engraved the sentence, "Let no one unacquainted with geometry enter here." There spoke, one would think, a follower of Pythagoras, but Plato regarded the study of geometry as a means of withdrawing the mind from material things and concentrating them on the abstract. When geometry was applied

to mechanical problems, and instruments were used in the investigation of physical phenomena, Plato indignantly asserted that this was to degrade geometry from the contemplation of objects of pure intelligence and make it the mere handmaid of sensation and the slave of matter.

Meditating on geometrical figures in the abstract, he came to the conclusion that the circle was the most perfect curve in nature, and hence that the heavenly bodies, being themselves perfect, must move in circles, and this fallacy remained one of the fundamental axioms of astronomy until it was finally disproved by Kepler nearly 2,000 years afterwards. So far as science was concerned, we might almost say that the Academy knew it not; natural philosophy was completely overshadowed by ethics. There was one pupil of the Academy, however, who was destined to outrival even the great figure of Plato, and that was ARISTOTLE, a man of a very different type from his teacher, for while Plato was a poetical idealist Aristotle was primarily a scientist. To him belongs the credit of rekindling the lamp just flickering to its extinction, and on his shoulders rests the responsibility of promulgating a system of education and learning which, in the later Middle Ages, came to be regarded as having almost the authority of the Scriptures themselves.

Aristotle was born at Stagira, a Greek town in the Macedonian peninsula of Chalcidice, in the year 384 B.C. His father, Nicomachus, was a member of the medical guild of the Asclepiadæ and physician to Amyntas II., king of Macedonia, and no doubt Aristotle's bent towards the study of natural history was in large measure determined by the atmosphere of medicine and biology that must have pervaded his father's home.

When eighteen years old, Aristotle came to Athens and matriculated in the famous school presided over by Plato, and with that distinguished man he remained for twenty years. He was a diligent and appreciative student, and Plato describes him as the intellect of his school. After Plato's death in 347 B.C., Aristotle, then thirty-eight years

ARISTOTLE.

(Statue in the Spada Palace, Rome)

of age, disappointed at not being nominated as head in his master's place, left Athens in company with a friend and fellow-student, Xenocrates, for the court of Hermias, ruler of Atarneus in Mysia, where he married either the daughter, sister, or, as some say, niece of Hermias. In 342 B.C. he became tutor to King Philip of Macedon's son, afterwards Alexander the Great. When Alexander departed on his Asian expedition in 334 Aristotle returned to Athens and opened the second great school outside the city gates, the Lyceum, the home of the Peripatetics, over which he presided for twelve years. On the collapse of the Macedonian empire after Alexander's death in 323, Aristotle got at loggerheads with the anti-Macedonian party and was compelled to leave Athens, retiring to Chalcis in Eubœa, where he died at the comparatively early age of sixty-two.

Such is briefly the epitome of the life of one who is generally regarded as the greatest philosopher of ancient times, a life that readily divides itself into four periods—eighteen years under his father's tuition, twenty years in the Academy, twelve years in Asia Minor and at Mitylene, and as Alexander's tutor, and twelve years as head of the Lyceum. His work may be summarized in a sentence by saying that he essayed to write a compendium of knowledge of all natural phenomena. He himself says, "I found no bases prepared, no models to copy, mine is the first step, and therefore a small one, though worked out with much thought and hard labour. It must be looked at as a first step and judged with indulgence." This is a very considerable claim and requires some justification, even though he makes the apology that it is only a first attempt. It will be advisable, therefore, to pause at this point and see whether it be strictly correct that Aristotle had "no bases prepared" and "no models to copy." This is all the more needful seeing that one distinguished writer (Sir R. A. Gregory) has recently (1917) given a very qualified estimate of Aristotle's labours. "Aristotle," he writes, "had long before insisted upon the collection of facts, and urged that we must 'first classify them, bring particular facts under

general heads and co-ordinate them into theories.' He collected so called 'facts' by hundreds, and proceeded to speculate upon them as if they were unalterable truths, whereas in many cases they were merely old women's tales or other hearsay evidence. His method was a logical machine which could produce reasonable results when provided with sound material to work upon, but not otherwise. Aristotle, and the school of thought he dominated for nearly two thousand years, knew nothing of the experimental method of inquiry."

Who then were the predecessors of Aristotle that in earlier times inquired into the secrets of Nature? We might name many, but perhaps half a dozen will serve to show that Aristotle's claim to have been the forerunner can scarcely be justified, and that he might have done much more had he only followed on the lines already laid down by those who lived more than a century before him Perhaps the general estimate of his achievements might have been modified had his predecessors left anything to speak of in writing, so that a more correct valuation might have been made of what he himself contributed to the advancement of science. But while their writings and teachings have come down to us only in sentences quoted from authors who lived several hundred years afterwards, Aristotle's were in large measure preserved, rediscovered and translated into Latin, and enthusiastically accepted in the thirteenth

The first of the ancient Greek philosophers who pried into the secrets of Nature was THALES, a native of Miletus, in Asia Minor, who lived to an extreme old age, having been born in 640 B.C. and dying in 546 B.C. He has been styled one of the
so much

account of political eminence—at least the other six, one of whom was Solon, were all noted legislators. He left no writings behind him, and all we know of himself and his teaching is derived from scattered references in works written long after his death. Theophrastus, a pupil of Aristotle, of whom more anon, states, indeed, that Thales left a treatise on Nautical Astronomy, but, if he did so, it also has disappeared. He is said to have been the founder of Greek Geometry, Astronomy and Philosophy, and such of his discoveries as have been recorded justify the title. No doubt much of his learning was derived from the Egyptians, for we know that he travelled extensively in Egypt.

His chief contribution to astronomical science, so far as we know, was the determination of the solstices and equinoxes—no mean achievement in itself when we remember the age in which he lived. He knew that the moon gave forth no light, but merely reflected that of the sun to our earth. He, it is true, believed in the eastern myth that asserted that the earth was a flat plain floating on water, but he deposed the sun and stars from their high estate as deities and said they were nothing but fiery balls. It is said that he predicted an eclipse of the sun to take place on May 28, 585, the occasion of a battle between the Medes and the Lydians; but although the truth of this story is regarded as doubtful, it is quite possible that Thales did predict such an eclipse, for that year at least, since he might well have had access to the astronomical tables that were circulated from the observatories we know to have existed in Mesopotamia. Taking all things into consideration, Thales has the credit of having been "the first to have set on foot the investigation of Nature among the Greeks."

ANAXIMANDER (611–547 B.C.), likewise a citizen of Miletus, and a pupil and friend of Thales, may also be regarded as a pioneer in the study of exact science. He taught the obliquity of the ecliptic—some say he actually discovered it; he described the phases of the moon, and must therefore have known that it revolved round the earth once a month; he introduced the gnomon and the

sundial into Greece, and prepared a map of the then known world. He explained thunder and lightning by saying they were "caused by the wind enclosed in a thick cloud, which by reason of its lightness breaketh forth violently, the rupture of the cloud maketh a crack and the divulsion by reason of the blackness causeth a flashing light." This is perhaps not a very satisfying explanation of the phenomenon to modern minds, but it is an improvement on the picture of Zeus throwing his thunderbolts down upon his erring subjects. (Anaximander's general philosophy is based on the existence of an "arche," or first principle which was an endless, limitless mass, in other words, a primeval chaos.) Out of this sprang the earth, which was at first surrounded by balls of fire, closely adherent to it, until they became detached as glowing bubbles of incandescent air, in which the gods resided. The earth gave rise to aquatic animals from whence man arose, and the earth and everything on it was destined to disappear once more into chaos.

But a greater man than either Thales or Anaximander was PYTHAGORAS. He was born, probably in 582 B.C., in the island of Samos in the Ægean, or, according to some authorities, on the Ionian coast In his earlier years he travelled extensively in Egypt and Babylonia, and even farther afield, for travelling in those days was one of the few ways of acquiring knowledge—an excellent way still for those who can afford it. About the year 529 B.C. he took up his abode at C
a secret society
pressed in later
politics. He died somewhere about 500 B.C., but the date is by no means certain.

His fame rests chiefly on the service he rendered to mathematics; indeed, it may be said that mathematics as a science began with Pythagoras It would be out of place to go into any detail on his views on geometry, but the student may be interested to know that it was Pythagoras who first demonstrated that the three angles of any triangle are together equal to two right angles, and that he was

also responsible for the famous 47th proposition of the first book of Euclid, viz. that the square on the hypotenuse of a triangle is equal to the sum of the squares on the other two sides.

The central feature of the teaching of Pythagoras was number, and he introduced a numerical symbolism indicated by dots, very much resembling the expression of numbers on the "cards" or "stones" used in the game of dominoes. He was the discoverer of the monochord, which consisted of a sounding box carrying a stretched wire, by varying the length and tension of which he obtained different notes of the musical scale—really the basic idea of modern stringed instruments like the piano. He further deduced the law that the pitch of the note was inversely proportional to the length of the vibrating string. This discovery led him to the rather vague generalization that "all things are numbers," and he applied his principle even to the heavenly bodies, saying that the whole celestial system was based on a musical scale. Each planet had a characteristic tone, those nearer the centre of revolution, moving more slowly, gave a note of low pitch, those farther away, moving more rapidly, gave a higher pitched note, the sphere of the fixed stars the highest of all. All these notes combined gave the "cosmic octave," and on this theory Pythagoras built the doctrine of the "Harmony of the Universe" or the "Music of the Spheres." The reason why men did not realize the existence of this music was because they had become so accustomed to hearing it always that it made no impression on their senses, just as, nowadays, the ocean-going traveller becomes unconscious of the throb of the propeller of a steamship after being a few days at sea.

In the early centuries before the Christian era philosophers regarded the universe as composed of four elements—earth, water, air and fire—and the Pythagoreans associated with these elements the four solids—the tetrahedron, the octahedron, the icosahedron and the cube. When they discovered the dodecahedron, a fifth element, the ether, had to be invented to complete the system. There is a

myth to the effect that the Pythagorean who discovered the fifth solid was drowned by the gods as a punishment for

glo
cen
nor
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moon, only reflected the light of the "central fire" upon the earth, and the reason men did not see this central fire was because it lay on the other and uninhabited side of the earth. Pythagoras explained the regular alternation of day and night in a very ingenious way. When the earth and the sun are both on the same side of the central fire they receive the reflected light from Hestia, and it is day; when the earth and the sun are on different sides no light is reflected and it is night, although light may still be reflected from the moon and stars. A pupil of Pythagoras, called Hicetas, went a step further, and held that all the heavenly bodies stood still and that the only mobile unit in the universe was the earth, which, by its rapid rotation on its own axis, produced the same effect as that which would result if the earth were stationary and the heavens revolved round it.

Even in the science of Geology Pythagoras and his ... ich are now ... Pythagoreans ... t that floods ... t sea might become land and conversely land might become sea.

> "The hills are shadows, and they flow
> From form to form and nothing stands."

Fossils *are* fossils—petrified by streams that can convert dead organisms into marble; marine shells are to be found on the mountain flanks now far removed from the sea;

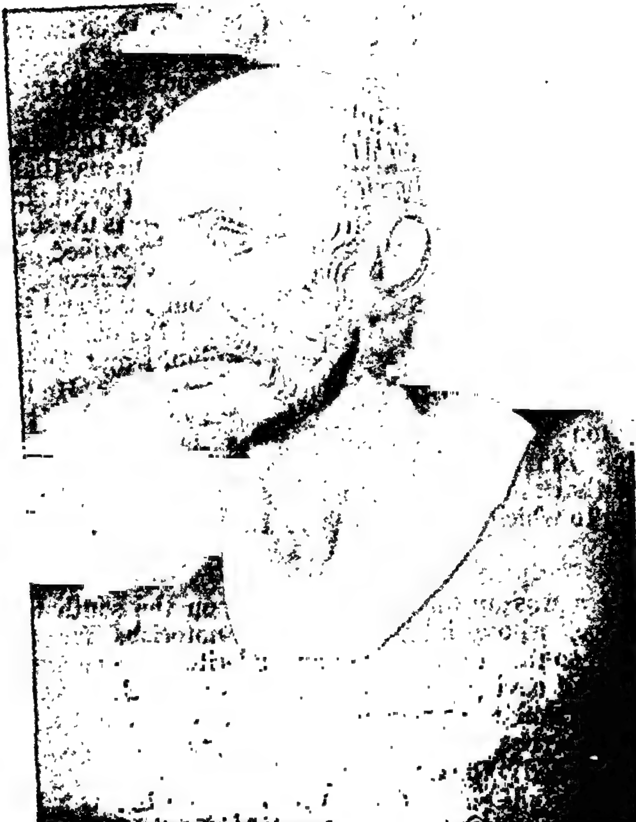
islands have once been united to mainlands and peninsulas have become islands by a cleft in the isthmus; volcanoes were once quiescent, and there would come a time when they would cease to be "burning mountains." It all reads like a chapter out of Hutton's *Theory of the Earth* published in 1795, or Lyell's *Principles of Geology* published in 1830; yet, if we are to accept Ovid's account, such advanced views were held and taught by Pythagoras some 500 years B.C.

Another of the great Ionian philosophers was ANAXAGORAS, who was born at Clazomenæ in Asia Minor, 499 B.C. Where and by whom he was educated we do not know, but we are told that he relinquished all his property and ceased participation in all civic and political affairs in order to devote himself entirely to the pursuit of knowledge. For thirty years of his life he lived in Athens, where he became the intimate friend of the statesman Pericles and the poet Euripides, and where he taught chiefly mathematics and astronomy. Like so many other inquirers into Nature's secrets in all ages, even to the present day, he suffered in the cause of truth or what he believed to be the truth, until finally he was arrested and imprisoned for impiety, and only managed to escape the later fate of Socrates by the influence of his powerful friend Pericles. Disgusted with the treatment he had received, he left Athens and retired to Lampsacus on the Dardanelles, where he died in 428 B.C.

Like Thales, Anaxagoras postulated a primeval chaos which first of all segregated into cold mist and warm ether. The mist then congealed into water, earth and rock; plants arose on the earth from seeds brought down by rain, although he does not suggest whence the seeds came; animals and man, on the other hand, were formed from moist warm clay—a notion reminding one strongly of similar statements in the book of Genesis, "and the Lord God formed man of the dust of the ground," and "out of the ground the Lord God formed every beast of the field and every fowl of the air." He studied and explained eclipses of the sun by saying that the moon came in between the

sun and the earth and so shut off its light, while an eclipse of the moon was due to the earth intervening between it and the sun. He also attempted to account for the rainbows and for meteors [illegible] enough to us, especially where he tells us that the sun is a ball of molten metal larger than the Peloponnesus, that the stars are masses of stone [illegible] [illegible] hills and valleys in the moon without a telescope, and believed that it was [illegible] own, and in all [illegible] the opinion that [illegible] and invisible [illegible] ory. He knew [illegible] I said that this inclination [illegible] solution.

Abdera was an ancient Greek city on the south coast of Thrace, whose inhabitants were notorious for their stupidity, so that to call a man an Abderite was a euphemistical way of saying he was a fool. Nevertheless Abdera was the birthplace of a man who was anything but a fool, viz. DEMOCRITUS, who was born there 470 or 460 B.C. He has been called "the laugh[illegible] a confirmed optimist and [illegible] joke to be enjoyed to th[illegible] in the Capitol Museum at [illegible] face obviously in the act of enjoying a joke either at his own or some one else's expense. About his life-history we know practically nothing; not even are we sure of the dates of his birth and death, the latter being placed anywhere between 380 and 357 B.C. In any case his optimistic and happy way of looking at the world enabled him to live to a ripe old age.



DEMOCRITUS.

(From the bust in the Hall of Philosophers, Capitol Museum, Rome.)

y his views on the com-
ıich have often been re-
modern Atomic Theory
tury ago. Democritus's
ısisted of infinitesimally
small particles or atoms, differing in size, weight, shape and arrangement; that these came together by the force of gravity, bombarding each other and flying off from each other in all directions, so producing a rotatory motion or vortex. At length the atoms found their proper combinations, and so the universe came into being—the result of what has been described as a "fortuitous concourse of atoms." These atoms Democritus regarded as eternal, invisible and indivisible. Nothing, therefore, comes into being and nothing perishes; the increase and decrease, the appearance and disappearance of compounds of atoms signify life and death. Motion also is eternal—in short, we have in his teaching the germ of the modern doctrine of

wonder, holding such views, that Democritus might well have forestalled Horace and written:

> "Dum loquimur, fugerit invida
> Ætas carpe diem!"

How his outlook on the universe was regarded by the mediæval writers of the Renaissance period may be gauged by the fact that Dante placed him in the first circle of the Inferno:

and then among these spirits Dante sees

> "Democritus, who says chance made the world."

But poor Democritus was in goodly company, for wi

him were Socrates, Plato, Thales, Anaxagoras, Zeno, Empedocles, Hippocrates and many another congenial spirit, who must have abundantly consoled and cheered the laughing Abderite.

The last of the pre-Aristotelian philosophers that need be mentioned was a man of a very different bent of mind. HIPPOCRATES was primarily a biologist, but with a limited outlook, seeing that he confined his observations to the human body and did not, like Aristotle, take any interest in the lower animals or in plants, save in their relation to man. He was born in the island of Cos in 460 B.C., and was a member of the medical guild of the Asclepiadæ. As in the case of the other scientists already discussed, we know little of his history. He was a pupil of Democritus, and had, like others, travelled over much of the countries bordering the eastern Mediterranean. So far as we know he died at Larissa in 375 B.C. at the age of eighty-five.

Previous to his day medicine was a priestly craft; ailments were inflictions of the gods, who had to be placated with presents, which naturally found their way into the coffers of the priests, and by sacrifices to be carried out in the temples dedicated to Æsculapius, the god of healing. Ignorance of the anatomy and physiology of the human body rendered any rational treatment of disease an impossibility. Hippocrates initiated an entirely different system. His theory was that there were in the body four humours or juices—blood, phlegm, yellow bile and black bile; that when these were present in the right proportions and correctly mixed the body was healthy, but when the proportions were incorrect illness resulted. It was, therefore, obviously the proper course to begin by diagnosing the disease—in short, Hippocrates was the first clinician.

The signal service Hippocrates rendered to medicine was to purge it from priestcraft and abstract philosophy and to base it on observation of the patient. His chief curative method—a very sound one—was the regulation of diet, coupled with reliance on the *Vis medicatrix Naturæ*.

These were great advances on the mystic rites carried out in the Æsculapian temples.

The works that have come down to us at second hand are by no means entirely from the pen of the "Father of Medicine"; they may rather be regarded as coming from the Hippocratean school of medical thought of which he was the founder.
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given a classification of animals of service as articles of food, together with incidental notes on their structure and habits. Something also was known of the pulse and of the construction of the heart, which was believed to distribute air, fire and movement throughout the different parts of the body. There is distinct evidence that dissection was practised, for
of internal or
acquired only
carefully, and in a work by an unknown writer on "Generation," a quite reasonable account is given of the germination of seeds and a comparison with the growth of plants from cuttings.

The beginnings of the science of biology were thus laid down and might have been greatly extended had the science not suffered, like all the other sciences, from the rapid rise of the study of Ethics under Socrates and Plato. One recent historian of the period has put the case in the following terse and vigorous language:

characteristic fruit we are not concerned. But the great successor and pupil of its founder gives us, in the *Timæus*, a picture of the depth to which natural science can be degraded in the effort to give a teleological meaning to all parts of the visible universe. The book and the picture which it draws, dark and repulsive to the mind trained in modern scientific method, enthralled the imagination of a

large part of mankind for wellnigh two thousand years. Organic nature appears in this work of Plato (427–347) as the degeneration of man whom the Creator has made most perfect. The school that held this view ultimately decayed as a result of its failure to advance positive knowledge. As the centuries went by its views became further and further divorced from phenomena, and the bizarre developments of later Neoplatonism * stand to this day as a warning against any system which shall neglect the investigation of nature. By its decay Platonism dragged science down, and destroyed by neglect nearly all earlier biological material. Mathematics, not being a phenomenal study, suited better the Neoplatonic mood and continued to advance, carrying astronomy with it for a while—astronomy that affected the life of man and that soon became the handmaid of astrology; medicine, too, that determined the conditions of man's life, was also cherished, though often mistakenly; but pure science was doomed. But though the ethical view of nature overwhelmed science in the end, the advent of the mighty figure of Aristotle (384–322) stayed the tide for a time." (C. Singer.)

After this long digression on pre-Aristotelians, we must now return to Aristotle himself. Of the large number of works that pass under his name quite half were not written by him, and are at most merely traditional sayings of his cast into essay form. Those that deal with physical as opposed to biological science, although they had a great influence for many centuries, are of little permanent value, and after the sixteenth century they fell into disrepute. His biological works, on the other hand, have stood the test of time and were regarded with respect by naturalists even as late as the nineteenth century.

The first thing that strikes us in these books and pamphlets is the enormous number of facts he accumulated, with reference to animals more especially. On the

* Neoplatonism may be described as a system of philosophy which attempts to replace the dualism of mind and matter by monism, which refers all the phenomena of the universe to a single principle, whatever that principle may be.

authority of that scientific gossip, Pliny, we learn that Aristotle's pupil, Alexander the Great, provided "thousands of men in every part of Asia and Greece" to collect animals of all kinds to be put at the disposal of his old tutor; but from other evidence it would seem that this was pure imagination on Pliny's part, for Aristotle, in all his works, never even says "thank you" for such assistance. Indeed, there is good reason to believe that Alexander and Aristotle were then not even on speaking terms. The inequality of the works themselves affords a basis in favour of the view that they were more in the nature of students' notebooks, or abstracts prepared by Aristotle himself for use in his lectures. In any case, they have gone through so many hands since they were first put together in the Lyceum that we may receive them more as *reliquiæ memoriæ* than as *ipsissima verba*.

The central idea of Aristotle's biology is the existence in every organism of a soul, or psyche—a "something that constitutes the form of living things"; and thus an inquiry into the nature of this soul is a fundamental duty on the part of the naturalist. "Nature," he thinks, "passes from lifeless objects to animals in such unbroken sequence, interposing between them beings which live and yet are not animals, that scarcely any difference seems to exist between two neighbouring groups owing to their close proximity." His notions of generation were those universally held almost up to our own times, viz., that the female provides the material of the embryo, while the male provides the soul or principle that makes life. Even the distinguished botanist Schleiden, as late as 1837, formulated an equally crude theory of the origin of a new plant by attempting to prove that the embryo was formed from the apex of the pollen tube, and that the ovule acted merely as a nutrient bed for its further development, thus degrading the part of the female in generation further than Aristotle did. In order to provide support for his views, Aristotle undertook researches in embryology, and followed, day by day, with wonderful precision, the

stages in the development of the hen's egg from its first incubation until the hatching of the chick. He discussed also, at considerable length, the differences between oviparous and viviparous animals, and was shrewd enough to observe that among fish—oviparous as a group—there were forms that were "externally viviparous." This peculiar condition was not thoroughly understood until the great German biologist, Johannes Müller, elucidated the whole story in 1840.

It would serve no useful purpose to follow the labyrinth of argument by which Aristotle attempts to explain the relationship of the psyche to the material body, for there he branches off into metaphysics pure and simple. According to some authors he is credited with having formulated a classification of animals, but this is quite incorrect. Nowhere in his writings does he do more than suggest certain groups, such as sanguineous and non-sanguineous, oviparous and viviparous, and so on, and any detailed classification that is formulated in his name is a deduction from his writings by some enthusiastic followers. For one thing, his ideas on species and genus are not comparable with our modern conceptions of these terms. For instance, he says: "It is in virtue of such similarity that Birds, Fishes, Cephalopoda and Testacea have been made to form each a separate genus." Indeed, in the use of these terms he is as vague as the modern journalist or manufacturer of crossword puzzles!

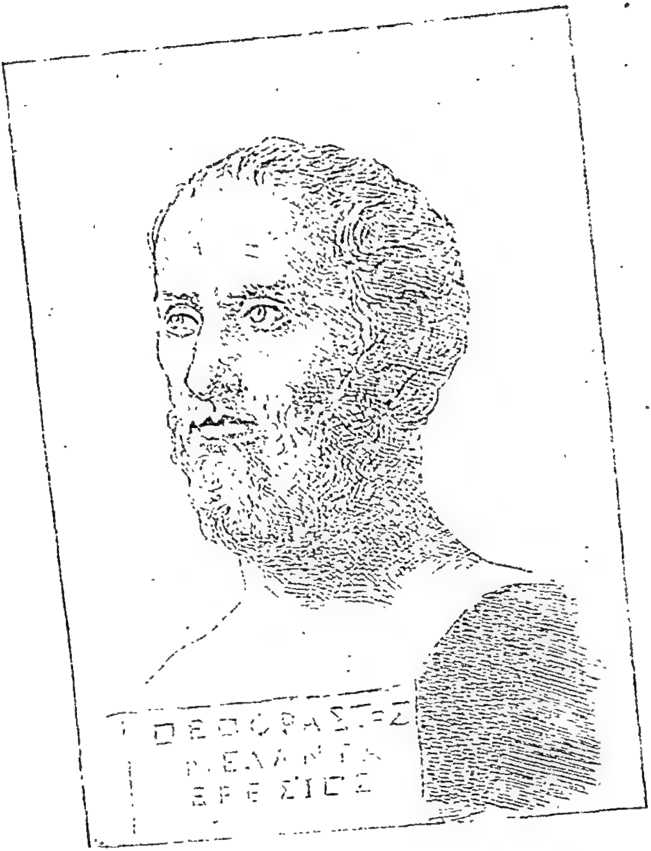
When we turn to his account of the structure of animals we find him on surer ground; there he shows himself as a competent comparative anatomist, and he excels in his descriptions of the habits of living animals. When he wanders off into physiology, however, his [illegible]able ignorance of physics allows him to exercise h[illegible]on in a way that is in marked contrast to the[illegible] tions and deductions made by the mem[illegible] pocratean school. He denied that the [illegible] of sensation, and regarded the spina[illegible] tissue that held the vertebræ togethe[illegible]

heart as composed of only three chambers, and believed that it absorbed air direct from the lung, and failed to see any difference between arteries and veins. In fact, he never appears to have dissected the human body, and bases all his theories on the observations of others, therein disobeying his own advice to investigators: "Let us understand the facts, and then we may seek the cause."

Aristotle wrote a treatise on plants, but this is entirely lost, although, doubtless, all that was valuable in it has been preserved in the writings of his pupil and successor, Theophrastus, the last of the Greek biologists. To this great man—the Father of Botany—we must now turn our attention.

The island of Mitylene, or Lesbos, in the Ægean, was famous in ancient days as the birthplace of several very distinguished personages—the lyric poets Alcæus and Sappho among the number—and it was noted as well for the excellency of its products; so much so, indeed, that the Greeks and Romans of later days, when desirous of commending a piece of music, a poem, or a cask of wine, spoke of it as Lesbian in praise of its quality. It was here, in the capital town of Eresos, that THEOPHRASTUS was born, 370 B.C. (or 382), the son of a wealthy fuller, called Melanthus. When only a boy he had been sent to the Academy at Athens and came under the influence of Plato and Aristotle, following the latter to the Lyceum when that school was founded. To Theophrastus Aristotle bequeathed his library, the richest then in existence, containing all the master's works—a fact that largely accounts for their preservation when the writings of preceding philosophers had disappeared.

The nucleus of the school was a chapel dedicated to the Muses, with two porticoes and rooms behind them which were gradually filled with books and all kinds of teaching material. The school included a garden, as the name, Peripatos, or the Walk, implies, and this was also included in Aristotle's bequest. The Academy likewise had its shady avenues, but the garden of the Lyceum was something more



THEOPHRASTUS.

[illegible] exercise and discussion: it [illegible] the forerunner of those that [illegible] f the universities of Europe from the sixteenth century onwards. "The existence of this Athenian botanic garden," writes one of the historians of Theophrastus (Lee Greene), "will explain how, occupied as he was with the management of, and also engaged in teaching in, a school of 2,000 students, with no time or opportunity for travel, he gained so intimate a knowledge of the life-histories of many plants. He had studied in that garden at morning, noon and evening for perhaps sixty years or more, when, almost a centenarian, he wrote such clauses as the following in his will: "I bequeath to my friends, specially named in this my Will, and to those that will spend their time with them in learning and philosophy, my garden, walk, and houses adjoining; upon condition, however, that none of them shall claim any particular property therein or alienate them from their proper use; but that they shall be enjoyed in common by them all as a sacred place where they may familiarly visit one another and discourse together like good friends."

"There are chapters in the *Historia Plantarum* that are so crowded with facts about seeds—seeds in process of germination, young seedling plants and older ones, observations upon this plant and that shrub as they appear in spring, summer, autumn and winter—that we should have wondered greatly how this most untravelled and sedentary of the great philosophers had gained all this minuteness of knowledge about the little things of plant life [illegible] this great garden in [illegible] is daily recreation alo[illegible]s, and within the bo[illegible]quest, they buried him." Theophrastus is said to have died in 288 B.C., but the dates both of his birth and death are uncertain.

The two principal works that Theophrastus left behind him—the *Historia Plantarum* and the *De Causis Plantarum*,—are not long books, but, at a time when all literature had

to be laboriously transcribed by hand, authors had to cultivate the virtue of brevity. The clear, simple and, for the period when they were written, accurate descriptions of plants and plant organs contrast markedly with the vague and often erroneous accounts given by authors who both preceded and succeeded him; indeed, Theophrastus's works read almost like a modern text-book.

He begins with an enumeration and definition of the parts of a plant—root, stem, branch, twig, leaf, flower and fruit, and describes the first four as permanent organs, while leaf, flower and fruit are classed as temporary or transient. The fruit is compared with the fœtus of an animal, something produced by it but not a part of it; the ovary is merely the first beginnings of the fruit. That plants as a group had sex like animals he did not realize, nor, for that matter, did any other botanist for two thousand years after his day; for although he talks of trees as "male" and "female," "male" stands to him as a synonym for "barren." Dates and figs, however, seem to have puzzled him not a little, for in speaking of these plants he distinctly suggests sexual fusion. He writes: "With dates it is helpful to bring the male to the female; for it is the male which causes the fruit to persist and ripen."

Plants, according to Theophrastus, are woody or herbaceous, and the herbaceous forms are classified as annual, biennial and perennial. His garden apparently contained very many cultivated herbs, shrubs and trees, for he mentions some five hundred species in his two books. He recognized that the aerial supports of an ivy were roots and not ... ls, and that all underground parts were not nec... ; in other words, he appreciated, to some ext... e diffe... tween true roots and rhizom... nd ... odified leaves, so that a ... egar... amorphosed branch. Th... s th... h nutrient materials a... e ... l defini-
on, as is al... h... ansport

of these nutrients to other parts. He did not attempt to define a leaf, but he described very fully the various types of leaf known to him.

Although he had no lenses, save those with which Nature had provided him, he shows himself possessed of a general knowledge of the rough anatomy of the different plant organs. He indicates the essential differences in stem, leaf and seed between what we now term Monocotyledons and Dicotyledons, and has a fairly clear conception of the mode of [illegible] he devotes two chapte[illegible] importance was added [illegible] Grew and Malpighi in the seventeenth century A.D.

Ignorant as he was of the precise functions of sepals, petals, stamens and carpels, he laid the foundations of our knowledge of floral morphology, for he distinguished between "leafy flowered" and "capillary flowered" plants —*i.e.* petaloid and apetalous flowers, between hypogynous, perigynous and epigynous insertion of floral leaves and stamens, and between centripetal inflorescences, like that of a foxglove, and centrifugal ones, like that of a chickweed. He knew that a capitulum consisted of many flowers closely grouped together—a fact not always realized by educated people even in this twentieth century, who persist in calling the inflorescence of such a plant as aster, a flower! The term "fruit" he applied to every structure that encloses seeds, and for the enclosing wall he coined the word "pericarp," a name still in use. He gave full accounts of the plants likely to be found in woodlands, marshes, lakes and rivers, and discussed their relations to their habitats—founding, in short, the department of botany now known as ecology. His books are full of hints to the agriculturist and the pharmacist, and a long section is devoted to timbers and their uses One curious notion was prevalent among the farmers of his day—viz the belief that in certain circumstances one kind of grain could turn into another; but Theophrastus will have none of that. "Some say that wheat has been known to be

was fostered by Ptolemy Philadelphus, who, with the aid of his able librarian Callimachus, collected all the works of Aristotle he could discover and added as well many Arabic and Jewish treatises. It is said, indeed, that his son, Ptolemy Euergetes, actually stole the original manuscripts of the Greek dramatists preserved in the archives of Athens, and compelled every notable that visited the city to leave behind him a copy of any book he might have brought with him. This great library in its heyday is said to have contained 700,000 volumes.

The subsequent history of this famous library may as well be given now. The story commonly told is that when the city was sacked by the Arabs in A.D. 641, a certain person, called John the Grammarian, a follower of Aristotle, begged that the library might be given to him, but that Omar replied that if the books contained the doctrines taught in the Koran they were superfluous, and that if they contradicted them they must be destroyed; so that either way the library was doomed. This story is in itself highly improbable, for the Arabs were great admirers of learning, and were not likely to countenance such wanton destruction. Besides, the narrative rests on the authority of a Christian writer of the name of Bar-Hebræus, who conveniently omits to mention that the library had already been pillaged by the Christian archbishop Theophilus, at the order of the Emperor Theodosius in A.D. 391. Whoever was the culprit, the fact remains that this, the first great public library, was destroyed—an irreparable loss to literature and science in the centuries that followed.

It is well for us to try and picture the Museum as it was in its palmy days, and attempt to realize the surroundings in which men, whose names are household words to us even now, lived and taught,—men like Euclid, Archimedes and Ptolemy—*no* relation of the reigning dynasty; and this has been done for us by Charles Kingsley in his well-known novel. In describing Hypatia's dwelling he says: "The attraction of the situation lay, perhaps, in the view which it commanded over the wall of the Museum gardens,

of flower-beds, shrubberies, fountains, statues, walks and alcoves, which had echoed for nearly seven hundred years to the wisdom of the Alexandrian sages and poets." (It should be remembered that Kingsley dates his novel from A.D. 415.) "School after school, they had all walked and taught and sung there, beneath the spreading planes and chestnuts, figs and palm-trees. The place seemed fragrant with all the riches of Greek thought and song, since the days when Ptolemy Philadelphus walked there with Euclid and Theocritus, Callimachus and Lycophron.

"On the left of the garden stretched the lofty eastern front of the Museum itself, with its picture galleries, halls of statuary, dining-halls and lecture-rooms; one huge wing containing that famous library, founded by the father of Philadelphus, which held in the time of Seneca, even after the destruction of a great part of it in Cæsar's siege, 400,000 manuscripts." (The burning of the library at this time is also denied) "There it towered up, the wonder of the world, its white roof bright against the rainless blue; and beyond it, among the ridges and pediments of noble buildings, a broad glimpse of the bright blue sea."

The history of the Alexandrine school of learning divides itself naturally into two periods The first dates from the foundation of the Museum in 300 B.C. to about 100 B.C., during which the school was a continuation of the old Athenian culture, though under the new conditions introduced by the Ptolemies. Thereafter Alexandria came more and more under the influence of Rome, and the ori

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where about 300 B.C. Of his date of birth or of death, of his parents and his teachers, or even of his early home, we are entirely ignorant. All we know is that he flourished in Alexandria soon after the foundation of the Museum, and probably came over with the first teachers induced to settle in Egypt by Ptolemy Soter. But if we know nothing of the author, the book of Euclid—really thirteen books, although only six are usually included in the text-book—is very well known to every one. Obviously we need not state what are the contents of this celebrated volume, once a universally used school-book, though now largely superseded. Briefly it is an introduction to Greek geometry, and is probably in the main a compilation from the works of Euclid's predecessors. "No other science has had any such single, permanently authoritative treatise." Euclid also wrote on Conic Sections, Division of Figures, Optics and Catoptrics (or reflections of light rays from plane, concave, and convex mirrors), and some of these works were used in the schools up to the end of the sixteenth century.

We know a good deal more of the life-history of the second great scientist of the Alexandrine School, ARCHIMEDES. He was born at Syracuse, 287 B.C., and was murdered at the capture of that city in 212 B.C. He is universally regarded as one of the greatest men in the whole history of physical science. He was at once a mathematician, a physicist, an engineer and an inventor; but, strangely enough, he himself despised his achievements in engineering and invention, although it is for some of these that he is popularly acclaimed. Who does not know the story of Hiero's crown? But lest it be unfamiliar to some reader it may be repeated here in the words of Vitruvius, one of Julius Cæsar's military engineers, who lived a few years before our era.

"Hiero, when he obtained the regal power in Syracuse, having, on the fortunate turn of his affairs, decreed a votive crown of gold to be placed in a certain temple to the immortal gods, commanded it to be made of great value, and assigned for this purpose an appropriate weight of the metal

to the manufacturer. The latter, in due time, presented the work to the king, beautifully wrought; and the weight appeared to correspond with that of the gold which had been assigned to it.

"But a report having been circulated that some of the gold had been abstracted, and that the deficiency thus caused had been supplied by silver, Hiero was indignant at the fraud, and, unacquainted with the method by which the theft might be detected, requested Archimedes to undertake to give it his attention. Charged with this commission, he, by chance, went to a bath, and, on jumping into the bath, perceived that, just in the proportion that his body became immersed, in the same proportion the water ran out of the vessel. Whence, catching at the method to be adopted for the solution of the proposition, he immediately followed it up, leapt out of the vessel in joy, and returning home naked cried out with a loud voice that he had found that of which he was in search, for he continued exclaiming, 'Eureka! Eureka! I have found it! I have found it!'"

What had he found? Much more than a way to trap [illegible]

water in the Egyptian irrigation works, and still known as [illegible]ent of Hiero [illegible] n of pulleys, [illegible] tones, beams [illegible] besiegers of Syracuse; but the story of his destruction of the Roman galleys by the concentration of solar heat rays upon them [illegible] is in all probability a fable.

[illegible] Euclid, [illegible] ation of [illegible] ignoble, [illegible] "every [illegible]

sort of art that lends itself to mere use and profit," as Plutarch says, yet never hesitated to apply his mathematical genius to works that might be of service to mankind.

In geometry his discoveries take the very first rank. He found that the circumference of a circle was rather more than three times its diameter, or that π, as we call it nowadays, was more than $3\frac{10}{71}$ and less than $3\frac{1}{7}$ of the diameter. He is credited also with the determination of the quadrature of the parabola and the area of an ellipse. He elucidated the principle of the spiral, and thus laid the foundation of the modern integral calculus. But he prided himself most on his discovery of the relation of the sphere to the cylinder, and at his own request this figure was engraved on his tombstone.

"Archimedes," writes one distinguished modern mathematician, "who combines a genius for mathematics with a physical insight, must rank with Newton as one of the founders of mathematical physics. The day (of the discovery of how to determine the specific gravity of a body) ought to be celebrated as the birthday of mathematical physics; the science came of age when Newton sat in his orchard."

Geometry and mechanics were not the only subjects advance in which is associated with the Alexandrine School. It was in Alexandria, for instance, that the anatomy of the human body was first studied, probably, as one writer suggests, because the Egyptians, accustomed as they were to the rough dissection necessary as a preliminary to embalming, were not so averse to anatomical investigations as were the Greeks. Hence opportunities were afforded to men like Herophilus and Erasistratus to correct the gross errors and ludicrous guesses made by Aristotle and his followers as to the structure and functions of the parts of the human body.

GALEN, born in A.D. 130 at Pergamum in Asia Minor, was another distinguished physician, who, after studying at Smyrna, joined the medical school at Alexandria. From thence he went to the court of Marcus Aurelius and became

medical adviser to his son, the Emperor Commodus, at Rome. He was a voluminous writer, and those of his works that were not destroyed in the subsequent burning of the Temple of Peace, formed the text-books of the medical schools for many hundred years.

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unknown. All that is fairly certain is that he wrote between A.D. 127 and 151, and lived somewhere near the temple of Serapis at Canopus close to Alexandria, "where they raised pillars, with the results of his astronomical discoveries engraved upon them." He stood in no blood relationship to the reigning dynasty, for the name was by no means an uncommon one in Egypt.

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plane and spherical trigonometry and the table of chords, and that his work was elaborated and systematized by Ptolemy, especially for use in astronomy. The work was called at first a "Syntax of Astronomy," but to this the Arabs prefixed the article *al-* and *megiste* or greatest, and hence it became known as the "Almagest."

First of all it may be well to try and obtain some notion of what Ptolemy had to work upon, viz the investigations of HIPPARCHUS, who lived from 190 to 120 B.C in the island of Rhodes, famous for its cultivation of roses, and also as one of the seven competitors for the honour of having been the birthplace of Homer.

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[illegible] proper name, Claudius [illegible] scientists of Alexandria, was not a Greek but a native of Egypt. The exact place of his birth and the dates of his birth and death are alike unknown. All that is fairly certain is that he wrote between A D. 127 and 151, and lived somewhere near the temple of Serapis at Canopus close to Alexandria, "where they raised pillars, with the results of his astronomical discoveries engraved upon them." He stood in no blood relationship to the reigning dynasty, for the name was by no means [illegible]

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naturally led from this to study the movements of the sun, moon and planets, and, in trying to explain these movements, he had to invent what we now call trigonometry. His greatest achievement, however, was the discovery of the precession of the equinoxes, a feat that, considering the means at his disposal, must be regarded with nothing short of amazement. It is not the purpose of this book to give, even in outline, all the great discoveries in astronomy or any other science, but only to give vignettes of the men and their works. In this case an exception may be made, for this is one of the really great discoveries of ancient times, not made in a moment, like that by Archimedes in his bath, but by long and careful observations, aided by a mathematical instrument the discoverer had to invent for himself.

Put in the briefest possible form, equinox means equal day and night always to one living on the Equator, but not to those living north or south of it, save once in spring, the vernal equinox, and once in autumn, the autumnal equinox. The position of these two equinoxes in the heavens must be of fundamental importance in considering the movements of the celestial bodies, and Hipparchus set about determining these two positions relatively to the stars in their vicinity. He discovered that these positions were not constant, but moved, extremely slowly it is true, one revolution taking twenty-five thousand years. Why? That was left for Newton to answer.

Ptolemy started with the assumption that the circle was the perfect curve, and that the celestial bodies moved in perfect curves, that is to say, in circles. The first question that strikes us is, how did he reach this conclusion? The earth is a sphere, he said, and proved it to be so very much in the same way as a schoolboy of the present day would prove it, and it was poised in space without any support. This was, of course, not an absolutely new idea, but it was an idea that Ptolemy proved to be a fact. So far so good, but now Ptolemy fell into error. He held the view that the stars (as opposed to planets) were sparkling points fixed on the inside of a gigantic sphere, with the earth at its centre,

and the question then arose, was the earth stationary and did the celestial sphere swing round it once in twenty-four hours, or was the celestial sphere a fixture and did the earth revolve on its own axis once in twenty-four hours? Either supposition would meet the case, but which was the correct one? If the celestial sphere moved, manifestly the speed of its revolution must be something stupendous; if the earth rotated, then why did not the atmosphere blow contrariwise to the rotation in a perpetual hurricane? Why was not a bird left miles behind every few seconds? We must bear in mind that Ptolemy was quite ignorant of the laws of motion and of the fact that the atmosphere and everything on the earth must rotate with it. He consequently decided in favour of the first hypothesis, viz. that the earth was stationary and that the jewelled sphere of the heavens revolved round it. This reasoning was entirely in accord with the observations of the "man in the street," and thus carried conviction to every one and continued to do so for more than a thousand years.

The next problems that Ptolemy had to face were the monthly movements of the moon, the annual movements of the sun, and the periodic movements of the planets. Still imbued with the belief that the circle was the perfect curve, he concluded that the moon completed the circle in a month, the sun its circle in a year, and the planets their respective circles in a variable number of months or years. But Ptolemy soon became aware of the fact that the revolutions of these celestial bodies could not be accounted for so simply. He saw, for example, that the planet Venus, although it went with the sun in its annual course, was, nevertheless, sometimes an evening star, i.e. appearing in the west after sunset, and sometimes a morning star appearing in the east, and that thus it could not perform its revolution round the earth in a perfect circle. To account for these irregularities he invented the hypothesis of "epicycles," which assumed that, in addition to following a circular orbit round the earth, the planet also moved in a much smaller circular orbit of its own, the centre of which

was on the major circle. How this complex system was first simplified and finally completely overthrown will become evident when we come to consider the astronomical advances made in the sixteenth century.

It was not only in astronomy that Ptolemy excelled; he prepared a geography of the earth, giving the latitude and longitude of some 5,000 places; he wrote also on sound and on optics, and in the latter treatise showed that a light ray passing from a rarer into a denser medium is bent out of the straight line.

With Ptolemy ends the glory of the Alexandrine School. After Alexandria came under the jurisdiction of Rome in the first century A.D. science ceased to exist, and it is a remarkable fact, to which attention has often been drawn, that neither the Romans themselves nor any of the peoples that came under their influence ever exhibited the slightest interest in scientific research. One critic, referring to this stagnation of inquiry into the phenomena of Nature, says: "The Romans, with their limited peasant horizon and their short-sighted practical simplicity, cherished always for pure science in their inmost hearts that peculiar mixture of suspicion and contempt which is so familiar to-day among the half educated. The arch dilettante Cicero boasts, even, that his countrymen, thank God! are not like those Greeks, but confine the study of mathematics and that sort of thing to the practically useful."

One exception may, perhaps, be made in favour of the Roman philosopher LUCRETIUS (98–55 B.C.), who, in his remarkable poem, *De rerum natura*, showed himself to be a scientific prophet and thinker of more than usual ability. Founding his meditations on the nature of the universe upon the philosophy of Empedocles (495–435 B.C.) and of Epicurus (341–270 B.C.), he, to some extent at least, foreshadowed the Newtonian theory of light and the Daltonian conception of the atomic constitution of matter, while he also enunciated views on the origin of life and the successive evolution of organisms that were the subjects of debate

among the biologists of the seventeenth and eighteenth centuries.

The general decadence of science in the early centuries of our era may be traced to two agencies—first, the ruthless, material destruction that accompanied the inroads of barbaric tribes, and, second, to the revolution in thought and outlook that is associated with the rise of Christianity. The whole system was in vivid contrast to the *un*-moral materialistic teaching of the Greeks, and necessarily to the frequently *im*-moral aspects of life that accompanied it, at least in its later stages. "Greek philosophy," said Justin Martyr, "can be learnt much better from the prophets;" "the Greek philosophers," said Clement, "are robbers and thieves who have given out as their own what they have taken from the Hebrew prophets;" Tertullian claimed that since the foundation of Christianity scientific research had become superfluous; and Lactantius, when writing on "The false wisdom of the philosophers," pours contempt upon the doctrine that the earth is a globe and that there exist people in the antipodes whose feet are higher than their heads! It does not need much imagination to picture the intellectual atmosphere in which science sickened and died, when leaders of the new creed taught their followers in terms like these.

The darkest period of the so-called Dark Ages was undoubtedly from the destruction of Alexandria by Omar in 641 to the first revival of learning under Charlemagne in 787, who established schools in connection with every [illegible] overcome the illiteracy [illegible] beginning arose what [illegible] a learning based on authority, not on experiment, a type of learning in which science had no place. And yet throughout these gloomy years and for long afterwards the scientific writings of the Greeks were in large measure preserved, awaiting the dawn of the New Age. Some of these were still in the possession of descendants of the old philosophers, some had been translated into Syriac and Arabic and became the heritage of

the Moors, who brought them over to Spain, and some had come from Byzantium through Italy.

To the Arabians we owe the beginnings of a new science, chemistry, whose basis is what we call alchemy, centring round the extraction of metals from ores and, especially, the attempts to transmute the baser metals into gold. These embryo chemists regarded a mythical personage called Hermes as the founder of their guild, and it is a curious verbal survival that to this day, when we fuse the open end of a glass tube in a blowpipe, we speak of hermetically sealing it. It is probable that to the Arabian alchemists we also owe the invention of gunpowder, although the credit is often given to Roger Bacon in the thirteenth century. They also were familiar with the fact that the application of heat to certain bodies resulted in the evolution of a gas or "spirit," which they could not see, but which they could collect in a bottle.

One of the best known of these pioneers was GEBER, who was born on the banks of the Euphrates about A.D. 830. To him we owe the chemical processes known as distillation and sublimation. By the former Geber was able to obtain pure alcohol from wine, and by the latter mercury from cinnabar. He found also that by heating a metal, such as iron or lead, in a crucible the metal increased in weight, but whence the extra weight came he was unable to determine. His most important discovery, however, was the method of manufacturing nitric and sulphuric acids. He found that with the aid of the former he could dissolve silver, and that when the nitric acid was mixed with sal-ammoniac or ammonium chloride—a substance obtained by burning camel dung, orginally found in deposits near the temple of Jupiter Ammon—he could dissolve gold as well.

Another of the Arabian scientists was ALHAZEN, who flourished about A.D. 1000. He was a Turk by birth, but lived most of his life in Spain. Although primarily an astronomer, what he is chiefly remembered by is his treatise on optics. This work is in some respects curiously anticipatory of Newton, and in others reminiscent of Ptolemy.

He was the first to say that the objects around us had no light in themselves, but were perceived by the eye because light from the sun or a lamp was reflected from them, and that the impression made on the retina was transmitted to the brain. He ingeniously explained why only one image is perceived, although we have two eyes, by saying that a ray from any object strikes corresponding parts of the eyes, but only one picture is transmitted to the brain. Ptolemy had already drawn attention to the refraction suffered by a ray of light in passing from a rarer to a denser medium. Alhazen also worked on this subject, and knowing that the earth was surrounded by an atmosphere that became gradually denser the nearer it was to the earth, deduced the fact that the sun's rays must be refracted on entering the atmosphere, so that we appear to see the sun after it has already set He applied the same principle to the explanation of the magnifying power of a convex lens.

But just as Greek science faded away from Alexandria after the Roman conquest and the establishment of Christian theology, so Arabian science and culture vanished in the tenth century and left scarcely a trace behind.

"The Golden Age of Moorish learning in the tenth century came and went, leaving behind it singularly few permanent results. Owing to the racial and religious hatreds of the time the Christian conquerors of the Moslems, like their Roman prototypes in the first few centuries after Christ, had small respect for Greek—and less for Mohammedan—learning. Hence, doubtless, it came about that to-day in Cordova, for example, almost no traces remain of that Arab learning of which it was once the celebrated seat. Even the site of its illustrious university has faded from memory, and only its great mosque (of which the heart is occupied by a Christian church) remains to be visible witness to Mohammedan Cordova The same is true of other once famous centres of Spanish Mohammedan-Greek learning Toledo still possesses some of its Arabian walls and gateways, and Seville its lovely Giralda—" the first astronomical observatory in Europe "—and its Tower

of Gold ; but it is only in the Alhambra of Granada that any adequate vision can be had of Mohammedan life and influence in Spain. Here the quiet, the seclusion, the rich ornamentation, and the music of abundant running waters, still communicate an impression of wealth, taste and power, and suggest possibilities of uninterrupted study and an intellectual life. Elsewhere, evidences of the Mohammedan love of inquiry, of libraries, of decoration, and even of fruits and gardens, have been almost wholly blotted out." (Sedgwick and Tyler.)

CHAPTER III

THE HERALD OF THE DAWN—ROGER BACON (1214–94)

IT is somewhat difficult for any one who is not a professed student of history to picture the condition of learning in the years that followed the signing of the Magna Charta. Our history books have been in the past, as a rule, too much concerned with political intrigues, squabbles between barons and kings and between kings and popes, to devote adequate space to the consideration of matters of more permanent value, the state of learning and science and the home-life of the people.

In western Europe during the eleventh, twelfth and thirteenth centuries there took place a notable revival of [illegible] ...though, in large [illegible] product of the [illegible] dogmatic, it is possible to recognize, both in the science and the literature of the time, a spirit born of independent thought on the part of men who resented the intolerance and narrow-mindedness of the monks.

With the features of this revival, in so far as it concerned literature and art, we have here nothing to do; we must confine ourselves strictly to searching for the first indications of a rebirth of scientific thought.

From the tenth century the name of Gerbert comes down to us as a mathematician of some note, who was for some time a schoolmaster at Rheims, but beyond inventing an abacus or arithmetical calculator and constructing a pipe organ, he does not seem to have done much towards the advance of science. Some notable progress was, how-

ever, made in medicine, especially by Constantine, surnamed Africanus from his place of birth. He appears to have travelled much in the East and to have brought back the knowledge he had acquired to Salerno, where he translated into Latin some of the Arabic works on medicine.

But perhaps the most important feature of the period from 1150 to the early decades of the thirteenth century was the energy with which translators turned into Latin, at that time the language of the erudite, the Arabic versions of the works of the ancient Greeks together with the commentaries on these classics by the Arabs themselves. Among these translations were the medical treatises of Galen and Avicenna and the writings of Ptolemy, and the study of these transcripts did much to awaken curiosity as to Nature and her ways among the inquirers of the thirteenth century. The outstanding author of antiquity, however, whose treatises captivated men's minds, was Aristotle, and strangely enough he was revered by clergy and laity alike. The mediæval theologians devoured the *Metaphysics*, although Aristotle's heterodox views on the creation of the world and the immortality of the soul must have been sore stumbling-blocks to them, had it not been for the casuistical commentaries of his translators, Albertus Magnus, the learned Bishop of Ratisbon, and his even more famous pupil, Thomas Aquinas.

It is curious and instructive to realize by what an erratic pathway the knowledge amassed by Aristotle and his contemporaries and successors reached the scholars of the west. "From Athens to Constantinople, from Constantinople to Bagdad, from Syria to Africa, from Africa to Spain," says a modern writer (Stocks), "came Aristotle to complete his empire in the west." The translation of Aristotle's works by the Arabian philosopher Averroës, who was a native of Cordova, has been described by Renan as "a Latin version of a Hebrew version of a commentary written on an Arabic version of a Syriac version of a Greek text"! And yet we are told that, in the university of Paris in the fourteenth century, professors had to swear that they would

teach nothing inconsistent with Aristotle and his commentator, Averroës!

Aristotle's works on natural science were also translated, as well as treatises by other Greek and Arabian writers dealing with various branches of mathematics and physics. In the former subject a new branch began to receive attention, viz. algebra, while methods of calculation were immensely improved and simplified by the introduction of the so-called Arabic notation, probably derived from India. The clumsy figures in use in Roman times gave place to the much more convenient system now universally adopted, although the Roman numerals still survive, *e.g.* on the title pages of many books published at the present day. In the most ancient of the sciences, astronomy, tables of the motions of the heavenly bodies were compiled with a view to a much-needed revision of the calendar But all these advances were greatly retarded by credulity and superstition. This was especially the case in medicine, where particular virtues were believed to reside in the most disagreeable objects. The various precious stones had magical virtues, which were able to confer on their fortunate owners wisdom, rhetorical powers, or success in life, and even ability to render their possessors invisible. The source of all these miraculous powers in animals, plants and minerals lay in the celestial bodies. The physician was primarily ... alike consulted the star-g... daily live... prolong life, or a philosopher's stone capable of transmuting the baser metals into gold, and accompanied his efforts by various incantations and magical rites. But, after all, the al... modern chemistry and perha... may...

the first compass, the manufacture of explosives (both, probably, of Chinese origin), of spectacle lenses, mechanical clocks, and the introduction of many industrial processes, such as the discovery of new dyes and methods of dyeing —the first beginnings of organic chemistry.

But perhaps the most important feature of this period was the development of the idea of experimentation as a means of gaining an insight into the laws of Nature. Authority alone was beginning to be regarded as an unreliable guide, unless supported by experimental proof. Among those who were mainly instrumental in bringing about this radical change in scientific thought was a Franciscan friar, called ROGER BACON, who has been well named "The Herald of the Dawn of Science."

Bacon was born at Ilchester in Somerset about the year 1214, and was educated at Oxford, where he took orders in 1233. In the following year he went to Paris, but was so disgusted with the teaching in that centre of learning that he devoted himself in private to the study of languages and to experimental research, deriving his scientific knowledge from the Arabian writers. In 1250 he returned to Oxford and became a Franciscan friar, still pursuing, however, his researches in a laboratory his friends had equipped for him. It is well to remember that magic and necromancy were at that time subjects of university lectures, and no doubt Bacon attended these courses of instruction, and probably subjected them to severe critical analysis; at all events, he was accused of heresy and of dealing in magic and the black arts in the secrecy of his laboratory, and got himself into so much disfavour with the theologians that he was recalled to Paris, there to remain "under supervision" of his Order, and forbidden to write anything for publication.

While in Paris, however, he was encouraged by the more enlightened Pope Clement IV. to compose a treatise on the sciences, and the result of his labours took the form of a work in three parts—the *Opus Majus*, the *Opus Minus* and the *Opus Tertium*—in which he propounded doctrines

that showed him to be a man born two centuries before his time. In 1268 he was permitted to return to Oxford, only to have his works condemned. The punishment meted out to him for his crime of speaking the truth was fourteen years' imprisonment. He was released in 1292, only to die in his eightieth year, leaving behind him the reputation of having been, as Von Humboldt says, "the greatest apparition of the Middle Ages."

Bacon's service to science was twofold: first and foremost, he enunciated principles on which, in his opinion, all progress must be based; and second, he made actual discoveries in many lines, but chiefly in physics. How many of these discoveries he actually made himself, and how many he adopted from the writings of the Arab philosophers, is not a matter of much importance, for he doubtless had access to many sources of information which are now lost to us, and of which, but for him, we should *probably have never heard.* The text of his whole teaching is the pre-eminence of experimental science—"Domina omnium scientiarum et finis totius speculationis." The words in which he formulates his views on this subject occur in the *Opus Majus*, and read more like an extract from an essay written in the twentieth century than the sayings of a Franciscan friar of the Middle Ages.

"[illegible] knowledge." [illegible]

no proof, nor does it remove doubt and cause the mind to rest in the conscious possession of truth, unless the truth is discovered by way of experience. *E.g.*, if any man who had never seen fire were to prove, by satisfactory argument, that fire burns and destroys things, the hearer's mind would not rest satisfied, nor would he avoid fire; until, by putting his hand or some combustible thing into it, he proved by actual experiment what the argument laid down. But after the experiment had been made, his mind receives certainty and rests in the possession of truth, which could not be given by argument, but only

by experience. And this is the case even in mathematics, where there is the strongest demonstration. For let any one have the clearest proof about an equilateral triangle without experience of it, his mind will never lay hold of the problem until he has actually before him the intersecting circles and the lines drawn from the point of section to the extremities of a straight line. He will then accept the conclusion with all satisfaction." He emphasizes this fundamental principle by pointing out that there are four chief causes of error: first, the acceptance of authority for proof of the existence of facts; second, custom or common belief; third, opinion as expressed by the unlearned multitude; and, lastly and most fatal of all, concealment of ignorance by pretending a knowledge that does not exist. These sources of error are considered in detail in the first part of the *Opus Majus*.

Part II. is a curious sop to the Church, and scarcely conforms with the views he expresses in Part I., wherein, as we have just seen, he definitely rejects authority as proof of the existence of things. In this section he argues that all true wisdom is contained in the Bible, and that the goal of philosophy is " to rise from the imperfect knowledge of created things to a knowledge of the Creator." The only way in which he can account for the erudition of the ancients who lived before the Bible was available, is by assuming that they obtained their insight into the phenomena of Nature from the Deity direct.

Part III. is more prosaic. It contains a plea for the necessity for an accurate knowledge of foreign languages, so that the student may be able to appreciate clearly what a writer aims at. Only after he has mastered the tongue in which a book is written, whether the subject be sacred or secular, will he be able to comprehend the subject itself, and to translate the treatise into the language he has selected as the medium for its publication.

Part IV. is a text-book on mathematics—" the alphabet of al[illegible]," as he terms it. The subject is comprehen[illegible] althou[illegible] marred by a ridiculous attempt

at showing how a knowledge of mathematics is essential to the proper understanding of theology. The section ends with a synopsis of geography and astronomy, the former of which is said to have been carefully studied by Columbus before he started on his adventurous voyage in search of the New World.

Part V. is primarily a treatise on perspective, and includes a description of the human eye, obviously from first-hand observation, a discussion of the principles of reflection and refraction, mirrors, lenses and so forth, much of it suggestive of the more accurate observations to be made in years to come, some of it, naturally, quite erroneous.

Part VI. is the most important section of the work, for in it he treats of experimental science—the *domina omnium scientiarum*. This part is so remarkable for the time in which it was written, indicating, as it does, Bacon's insight into matters that had to wait three hundred years for their clear elucidation, that a précis, at least, must be given of its contents.

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It is only by the aid of experimental science that we shall be able to disabuse men of the fraudulent tricks by which magicians have imposed on them. Experimental science has three characteristics, or prerogatives, as Bacon terms them. The first is that it tests all the conclusions of the other sciences, where the principles are discovered by experiment, and the conclusions arrived at by reasoning. Then follows a remarkable discussion on the nature of the rainbow. Having observed a rainbow in the sky, the experimenter seeks for objects in which the colours of the rainbow appear in the same order, and he finds them in al[l] crystals of hexagonal shape when placed in the sun's rays, in water-drips from an oar or a water-wheel, or from the dew

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on the grass in the early morning. The height of the bow in the sky, he finds, varies inversely as the sun's height, the bow always being opposite the sun. He goes on to inquire whether the colours in the clouds are real? He finds that on moving parallel to the rainbow it follows with an equal velocity, and concludes that each of a hundred men standing in a row sees a different rainbow towards the centre of which his own shadow would point. His final explanation of the phenomenon is that each drop of rain in the cloud acts like a spherical mirror, but since these drops are so small, and so close together, the effect is that of a continuous image rather than a multitude of images, while the colour is due to the distortion of the image caused by the sphericity of the mirror. Bacon next refers to the popular notion that the different colours of the rainbow are due to variation in the texture of the cloud, the denser parts giving violet and blue, and the less dense red and orange. But this cannot be the reason, for we see the same colours in a dewdrop or a crystal, where there are no differences in density. Lunar rainbows were believed to occur only at intervals of fifty years, but Bacon holds that they may occur at any period of full moon, provided the atmospheric conditions be suitable. He observed that the same colour continues all round the ring in a circle, and concludes that all parts preserve the same relation of the solar ray to the eye. Why is the space within the circle colourless? Because from the points in this central area rays equal to the angle of incidence are not reflected to the eye. As one of his biographers says, the whole investigation is "a very fine specimen of inductive research."

The other prerogatives of experimental science are that it discovers truths which other sciences could never reach, and that it investigates the secrets of Nature and opens to us a knowledge of past and future.

It is claimed for Bacon that he invented gunpowder from a mixture of saltpetre, charcoal and sulphur; but it is more probable that he learned of this explosive from the Arabs, who learnt it from the Chinese, for guns were in use

long before his day. He knew that a candle went out if it was covered by a bell jar, anticipating Black's discoveries five hundred [illegible]
prophecy tha[illegible]
without wind[illegible]
that people will fly like birds! He attributed the ebb and flow of tides to the moon's activity, and laid down the principles on which the calendar must be reformed. Although he made no attempt at solving astronomical problems, he yet expressed the view that the earth was a mere speck in the centre of the heavens.

Some would give Bacon the credit of inventing the telescope, but this achievement must be reserved for Galileo. Nevertheless he understood its principle, as is evidenced by the following words: "We can place transparent bodies in such a form and position between our eyes and other objects that the rays shall be refracted and bent towards any place we please, so that we shall see the object near at hand, or at a distance, under any angle we please; and thus from an incredible distance we may read the smallest letter, and may number the smallest particles of sand, by reason of the greatness of the angle under which they appear."

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a [illegible]
n [illegible]
rank than Roger Bacon. He is in every way worthy to be placed beside Albertus Magnus, Bonaventura, and Thomas Aquinas. These had an infinitely wider renown in their day, but modern criticism has restored the balance [illegible]

[illegible]

more just and clear than are even those of his more celebrated namesake. In this view there is certainly some truth, but it is much exaggerated. As a general rule, no man can be completely dissevered from his national ante-

cedents and surroundings, and Bacon is not an exception. Those who take up such an extreme position regarding his merits have known too little of the state of contemporary science, and have limited their comparison to the works of the scholastic theologians. We never find in Bacon himself any consciousness of originality; he is rather a keen and systematic thinker, working in a well-beaten track, from which his contemporaries were being drawn by theology and metaphysics." (Prof. R. Adamson, *Encyclopædia Britannica*.)

CHAPTER IV

THE DAWN OF MODERN SCIENCE

DURING the century and a half following the death of Roger Bacon science has very little to record. Perhaps the most notable event in experimental physics

accorded to a certain mythical personage called Flavio Gioja, but it seems highly probable that the properties of the loadstone or "leading stone" (magnetic iron oxide), were known, several centuries before, both to the Chinese and to the Arabs, and used by them as a means of determining a ship's direction at sea. The use of these instruments was regarded about this time as savouring of the black art. "No mariner," writes one of these ultra-superstitious persons, "dares to use it lest he should be suspected of being a magician; nor would the sailors venture to go to sea under the command of a man using an instrument which so much appears to be under the influence of the powers below." This was the general attitude taken by the public towards scientific inventions in the thirteenth and fourteenth centuries.

The invention—if it may be so called—of printing from movable type was a fact accomplished, it is said, by
Johann Gutenberg
of that city namec
pleted the printing of the Bible in 1455, and, a few years later, printing presses were set up in Italy, France and England. Here again the Germans were forestalled by the Chinese, for there is evidence that printing was carried

out by that ingenious nation in the end of the seventh century. It is impossible to exaggerate the importance of this innovation, for, so long as books could be multiplied only by laborious transcription by hand, it was difficult to make discoveries known save to a select few. Further, the ancient texts could now be acquired and studied with comparative ease, and not, as heretofore, only in manuscript form in some remote library. To spread the light was almost as important as to create it. Incidentally it is curious how so many contractions and word-signs employed in the original manuscripts, doubtless used by the scribes with the view of lessening their labours, reappear in the early printed books, although there was now no obvious gain by their retention. Men could now read where they previously listened, and consequently a popular education became possible. Printing, indeed, may be looked upon as one of the first causes of the birth of the Revival of Learning.

It was soon after this great advance in the method of disseminating knowledge that men began to speculate as to the possible existence of other lands beyond the Pillars of Hercules; and the pioneer was the Genoese, Christopher Columbus, who, with three small ships, no larger than modern coasters, sailed from Cadiz in 1492 to find a new route to the East Indies and "far Cathay." He failed in that ambition, for he found not the other shore of an old continent, but an entirely new one.

> "What treasures found he? chains and pains and sorrow,
> Yea, all the wealth those noble seekers find
> Whose footfalls mark the music of mankind!
> 'Twas his to lend a life: 'twas man's to borrow:
> 'Twas his to make, but not to share, the morrow."

Five years later, in 1497, Vasco da Gama, a Portuguese circumnavigated Africa and brought home confirmator[y] evidence of the sphericity of the earth by recording in h[is] log the rise of new constellations in the southern heavens an[d] the sinking of the old ones beneath the northern horizon.

Yet a third intrepid mariner, the Spaniard, really Portuguese, Magellan, set off in 1519 to accomplish what was a herculean task in those days, viz. the circumnavigation of the globe. Steering for South America, he discovered the Straits that are now known by his name, crossed the Pacific Ocean for the first time, and, although he himself perished on the way, his second in command brought the ship safely back to Seville in 1522, thus once and for all establishing as a fact what had been so often asserted by the later—and even the early—astronomers, viz. that the earth was a globe.

It will be remembered that we saw in Chapter II. how Ptolemy was faced with the task of deciding between two hypotheses, either that the earth was the centre of the universe, and that the sun, moon and planets swung round it in great concentric circles, while outside "the spangled heavens, a shining frame," forming the limit of the visible universe, moved round the whole with incredible velocity, or that all these celestial spheres were fixtures, and that it was the earth alone that moved, rotating on its axis every twenty-four hours. The difficulties, he fancied, that stood in the way of accepting the second hypothesis were far greater than those that confronted him in accepting the former, although the exact reverse was the truth. Ptolemy cast his vote, therefore, for a stationary earth and mobile heavens, and this, the so-called Ptolemaic System, held the field for fourteen hundred years.

In 1473 there was born a man who also weighed in the balance the two alternatives that had caused Ptolemy so much perturbation of spirit, and after pondering deeply over the matter finally decided that Ptolemy was wrong, and that the second hypothesis was the correct one. This man was Nicolaus Copernicus or Copernik. "Having turned over in my mind for a long time," he writes, "this uncertainty of the traditional mathematical methods of calculating the motions of the celestial bodies, I began to grow disgusted that no more consistent scheme of the

movements of the mechanism of the universe, set up for our benefit by that best and most law-abiding Architect of all things, was agreed upon by philosophers who otherwise investigate so carefully the most minute details of this world. Wherefore I undertook the task of re-reading the books of all the philosophers I could get access to, to see whether any one ever was of the opinion that the motions of the celestial bodies were other than those postulated by the men who taught mathematics in the schools. And I found first, indeed, in Cicero, that Hicetas perceived that the earth moved; and afterwards, in Plutarch, I found that some others were of this opinion. . . . Taking this as a starting-point, I began to consider the mobility of the earth."

Now the gauntlet was thrown down, and the supremacy of Ptolemy was challenged.

Copernicus was the son of a merchant of Thorn, a town on the ancient borders of Prussia and Poland, where the future astronomer was born on February 19, 1473. He was educated under the guardianship of his uncle, the bishop of Ermland, and, at the age of eighteen, entered the university of Cracow, where he studied mathematics, optics and perspective. From Cracow he went to Bologna, and became a student of canon law, and, in 1497, was appointed a canon of Frauenburg, the cathedral city of Ermland. In 1500 he became a lecturer on astronomy in the university of Rome, and then went to Padua to study medicine. In 1505 he left Italy for good, and returned to his native country. Although a canon of the cathedral he never became a priest, but lived at his uncle's castle of Heilsberg, some fifty miles from Frauenburg. When the bishop died in 1512 he took up his residence in that city, living on the income of his canonry, and, in addition to studying astronomy, fulfilled various duties of a civic character, and, in 1523, was administrator-general of the diocese. He is described as a retiring, scholarly man and an omnivorous reader. He cannot be regarded as a brilliant genius, and does not compare in intellectual ability with any of his three great successors, Kepler, Galileo

and Newton. He was quite indifferent to any fame likely to accrue from the publication of his works, and loathed the idea of controversy. Save for a small treatise on

NICOLAUS COPERNICUS, 1473-1543.
(From an engraving after the painting in the possession of the Royal Society)

trigonometry and some theological works, he published nothing until, at the urgent request of his friends, he consented to the printing of his famous book, *De Revolutionibus Orbium Cœlestium.* It was published on the day of his death, May 24, 1543, and all that he could do was to touch

it with his nerveless hands, for he had been stricken with paralysis in the preceding year. Perhaps it was just as well that the birth-day of his book should have been also the death-day of its author, for although it was dedicated to Pope Paul III., and its publication paid for by a cardinal of the Church, who thus had more or less made themselves sponsors for its production, it is more than likely that when these high dignitaries had once realized the nature of its contents they might have been among the first to glorify it by placing it upon the Index, and to degrade its author by haling him before the Inquisition. Mercifully, Copernicus was spared the indignities and punishments heaped upon his successor, Galileo, and his work remains as one of the greatest steps ever taken in science.

The keynote of the *De Revolutionibus* is the theory of the heavens guessed at by Pythagoras, viz. that the sun is the centre of the universe, round which all the planets, including the earth, revolve. It is well to try and realize what such a change in outlook really meant. Hitherto the earth was believed to be the central feature in the universe, and sun, moon, planets and stars were all subordinate to it. People believed in the literal truth of the words of Genesis: "Let there be lights in the firmament of the heaven to divide the day from the night . . . and God made the two great lights; the greater light to rule the day and the lesser light to rule the night . . . he made the stars also," and man was the wonderful being for whose benefit all this galaxy of celestial lights was created. But if the earth were only an insignificant particle in a stupendous whole and entirely subordinate to the sun, and if the planets were other worlds, some of them many times the size of the earth, where did man come in? What was his status in the universe? Surely the whole elaborate architecture of theological doctrine would crash to the ground, the teachings of the Church would be void and meaningless! Such an outlook could not possibly be accepted; it was the rankest heresy; there was nothing to be done but stamp it out!

It is true that the new conception of the universe and man's place in it did not "catch on" just at once, partly because few people were able to follow a doctrine written in monkish Latin and hidden away in a ponderous folio, *and partly because their criticism—even if they understood* what it all meant—was in large measure disarmed by the fact that the book was written by an ecclesiastic and dedicated to the Pope, who must have known and approved of its contents.

In the first place, Copernicus established clearly what Ptolemy found himself unable to accept, viz. that the apparent motion of the heavenly bodies was due to the daily rotation of the earth on its own axis. Just as in a smooth-running express train the woods, fields and villages seem to be flying past us at sixty miles an hour, and we, in the express, appear to be standing still, so, according to Ptolemy, the sun, moon and stars are flying round us at an incredible speed, while the earth is stationary. But Copernicus pointed out that the same effect would be brought about if all the members of "the spangled host" were fixtures and if the earth were the moving body He said that the atmosphere and all the loose objects on the earth accompanied it in its rotation, like the clothes upon a person running along a street. Ptolemy conceived the stars as fixed in some way or another in a celestial sphere, but Copernicus pointed out that this involved all the stars being at the same distance from the earth—a condition of things which was, to say the least of it, highly improbable. Moreover, he naturally asked himself what could the sphere be made of? It could not be liquid or gaseous, otherwise the stars moving with it with incredible velocity would tumble out of it; and it could not be solid, even though transparent, for how then could anything, such as a comet, penetrate it? Besides, what was beyond the sphere? Reject the idea of a celestial sphere, and then the stars might be relatively near or very far off. The sphere became, in short, merely a convenient geometrical conception—a celestial map on which we might indicate the position of the stars with

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regard to each other as viewed by an observer on the earth.

Copernicus next set about explaining the apparently retrograde movements of Mars. Both Mars and the earth, according to him, were revolving round the sun, and if this revolution was carried out at the same relative rate by both planets, Mars would appear not to be moving at all—just as two trains, both moving at sixty miles an hour on parallel sets of rails, appear to be stationary. But if one be moving at sixty miles an hour and the other at forty, the faster train will forge ahead, and an observer at a carriage window, not looking at the wheels of the slower train, will gain the impression that it is moving backwards, although it be still pressing forwards at forty miles an hour. Copernicus showed how these principles might be applied to the apparent irregularities in the movements of all the planets, and he may, in this way, be said to have laid the foundations of modern astronomy.

As one of his biographers (E. J. C. Morton) has written, "Copernicus cannot be said to have flooded with light the dark places of Nature, in the way that one stupendous mind subsequently did; but still, as we look back through the long vista of the history of science, the dim, titanic figure of the old monk seems to rear itself out of the dull flats around it, pierces with its head the mists that overshadow them, and catches the first gleam of the rising sun—

> " 'Like some iron peak, by the Creator
> Fired with the red glow of the rushing morn.' "

But astronomy was not the only science that came to life again, though in another garb, in the beginning of the sixteenth century. Biology and its attendant, Medicine, once more began to occupy men's thoughts, and while Copernicus was exploring and interpreting the mysteries of the infinitely vast surroundings in which man found himself placed, there were others who faced the equally difficult problem of discovering of what man himself was made.

During the fifteenth century there had been two great influences at work, unconsciously, perhaps, but none the less effectively, hastening the new awakening and stimulating inquiry into the truth of the dogmas that had hitherto passed under the name of knowledge One of these, as we have already seen, was the invention of printing from movable type, the other was the wholesale foundation of universities Every city of any importance boasted of its own seat of learning of varying repute, according to the renown of the teachers associated with it.

It was during this, the springtime of science, that there appeared on the horizon one of the most remarkable men that Europe had as yet seen—remarkable not so much for the discoveries that he made, as for the influence he exerted on the minds both of his followers and of his opponents This man was Theophrastus Bombastus von Hohenheim, commonly called PARACELSUS. He has been lauded to the skies as a most distinguished physician, a wise teacher, a great reformer, and a sincere, pious and unselfish man On the other hand, he has been condemned as an egotist, an ignorant charlatan, a drunken braggart and a superstitious visionary. Which view of his attainments is the correct one? or does the truth lie midway between these contradictory estimates—as the truth so often does? The second view is, perhaps, that most generally held, seeing that it is crystallized in a dictionary word—"bombast." A very able analysis of the life and writings of Paracelsus by the American professor of chemistry, Stillman, enables us to acquire a reliable conception of this mystical personality and of the opinions he held.

Paracelsus was born at Einsiedeln, in Switzerland, in December 1493 (twenty years, therefore, after Copernicus), the son of a village doctor, who, doubtless, had much to do with his son's primary education. At an early date he appears to have turned his attention to chemistry, for we hear of him working at metallurgy at a mining school in the Tyrol After several years of travel in various parts of Europe as an army surgeon, he finally settled at Basel

THEOPHRASTUS PARACELSUS.
(From the painting by Rubens in the Brussels Gallery.)

as "town physician," or medical officer of health, as we would call the post, and professor at the university, where he was a colleague of the famous Erasmus, and there he remained till 1528, when, as he himself bewails, "a rejected member of the university, a heretic of the profession, a misleader of scholars," he resumed his wanderings. These, and his life also, came to a close in the Austrian city of Salzburg in September 1541—"weak in body, yet quite sound in reason, mind, and spirit."

Medicine in the days of Paracelsus was in an extremely backward condition. *Its basis was the works of Hippocrates,* Galen, and the translations of Arabic treatises on the subject prepared by Avicenna and Averrhoës, and the authority of these in medicine was supreme. Medicine had become a rigid caste, and its bible was regarded as infallible. There were doubters and critics, of course, but theirs were voices crying in the wilderness. Erasmus, a contemporary of Paracelsus, says in his *Praise of Folly*, ". . . and indeed the whole art as it is now practised, is but one incorporated compound of craft and imposture" Another contemporary, Agrippa von Nettesheim, gives us a lurid picture of the physicians of his time. "The greatest reputation," he writes, "is attained by those physicians who are recommended by splendid costumes, many rings and jewels, a distant fatherland, tedious travels, a strange religion—especially the Hindu or Mohammedan, and who combine with these a monstrous shamelessness in the praising of their medicines and cures. They observe times and hours most exactly, dispense their medicines always according to the astrological calendar, and hang all kinds of amulets on the patient. Simple and native medicines are quite neglected. Costly foreign remedies are preferred, which latter are mixed in such enormous numbers that the action of one is counteracted by that of another, so that no human sagacity can foresee the effects that will arise from such an abominable mixture."

The common beliefs held as to the causes of disease were so ludicrous that it is no wonder that there was room

for a man with the courage and passionate intensity of character of Paracelsus to raise a strenuous protest against the absurdities that stood for medical practice in the early sixteenth century. The causes of disease were five in number:

(1) Disease comes from God by His direct volition as a warning or as a punishment, therefore the Church is the natural means by which the divine mercy may be invoked to relieve the suffering.

(2) Disease comes from the devil or his agents, and to remedy mischief of this sort the white magic of the Church may be effective, viz. prayers, penances, and exorcisms; or the black magic of the sorcerer, or an unholy alliance with the powers of evil.

(3) Disease comes from the stars, and in such cases the physician must be a skilled astrologer who knew the secrets of the heavens, when to prepare his remedies and also when the stars indicated a favourable time for their administration.

(4) Disease comes from disturbances in the four humours of the body, viz. blood, phlegm, yellow bile and black bile, and here the prescriptions of Galen were alone likely to be of service.

(5) Disease is due to the lack of something in the body, which could only be replaced by almost incredible and repulsive remedies.

Like his great predecessor Hippocrates, Paracelsus was a firm believer in the *Vis medicatrix Naturæ*. "In Nature's battle against disease," he writes, "the physician is but the helper, who furnishes Nature with weapons; the apothecary is but the smith who forges them. The business of the physician is therefore to give Nature what she needs for her battle. Nature is the physician."

"These medical theories of Paracelsus were extremely heretical in the eyes of the medical profession of the time," writes Stillman. "It was not possible for him to have publicly maintained his theories without exciting the opposition of the medical faculties and practitioners. Least

of all was that possible in the universities, which were the

to him in his travels in his own and in foreign lands, and his sojourning among all classes of people, the remedies and treatments used by all kinds of healers and the homely remedies in use among the common people. His chemical knowledge and his chemical theories of the nature of vegetable and mineral substances in their relation to the nature of man doubtless suggested new ideas, and these he tested by observation and experience. . . . Having cut loose from the dominant Galenism of his time, he determined to preach and teach that the basis of the medical science of the future should be the study of Nature, observation of the patient, experiment and experience, and not the infallible dogmas of authors long dead."

That every disease had a remedy was an axiom with him, and he scorned to accept the doctrine that any ailment was incurable. "Oh, you foolish heads," he says, speaking of his opponents, "who has authorized you to speak, because you know nothing and can accomplish nothing? Why do you not consider the saying of Christ, where He says that the sick have need of a physician? Are those not sick that ye abandon? I think so. If then they are sick as proven, then they need the physician. If then they need the physician, why do you say they cannot be helped? You say it because you are born from the labyrinth of errors of medicine, and ignorance is your mother. Every disease has its medicine"

Another of his principles related to the treatment of wounds and sores. The method in use was to sew or plaster them up, or to cover them with poultices and other nauseous concoctions; but Paracelsus preached the doctrine of the great surgeon of the nineteenth century, Lister, that the proper treatment was cleanliness, protection from dirt and "external enemies," and regulation of diet, and trusting in Nature to effect a cure. "Every wound heals

itself if it be only kept clean," he asserted, and what modern surgeon would contradict him?

The chemists of the sixteenth century were of two types: they were either practical men who worked in mines or metallurgical works, potteries, or various other industries, or alchemists who were for ever striving to transmute the baser metals into gold or to find the elixir that would confer perennial youth. Paracelsus's knowledge of the works of both these types of chemist was extensive, of the former by practical experience, and of the latter by the study of the lore of the Chaldees, the Egyptians and the Arabs. He made no epoch-making discovery, nor did he propound any startling chemical theory of the nature of matter; but he did something just as great—he opened up a new field of investigation in the preparation and application of chemical substances in the art of medicine.

To quote again from Stillman: "While it has been the fortune of many prominent names in the history of civilization that their best thoughts have been remembered and their weaknesses and vagaries overlooked, it was the fate of Paracelsus that for centuries his shortcomings were emphasized and exaggerated, and his merits minimized. The period of his activity was distinguished by the development of revolutionary ideas, when the spirit of modernism was struggling to free itself from the bondage of mediæval scholasticism. And the most revolutionary idea was that of independence in questioning and judging authoritative dogmas sanctioned by centuries of acceptance. In this respect Paracelsus was among the greatest of his century. That his method was not that of modern science may be freely admitted, and yet he may be credited with some realization of the necessity of such method and of foreseeing, as he preached, that *Experientia est Scientia.*"

There are several other names of men of this period that force themselves on our notice as pioneers in the medical art. One of these is VESALIUS (1514–64), professor of anatomy in the university of Padua (p. 190), who published an important book, called *The Great Anatomy.*

His chief merit lies in the fact that he had the courage—great in those days—to dissect the human body and to demonstrate structures that had never, hitherto, been investigated. He was driven from his chair by the Inquisition, sentenced to perform a pilgrimage to Jerusalem, and was drowned on his return journey. Another contemporary of Paracelsus was EUSTACHIUS of Naples (1500–74), whose name is preserved in the title given to the tube connecting the throat with the middle ear. There is also FALLOPIUS of Modena (1523–62), professor in Pisa and afterwards Padua, remembered by his discovery of the human oviducts which bear his name. Yet another, ... sician, SERVETUS ... The pursuit of ... we have already seen, attended with very grave risk.

In the meantime another biological science had come into being, or rather had been reborn, viz. botany We have seen already that its foundations were laid by Theophrastus in the fourth century B.C., in the garden of the Lyceum at Athens, and from that day until well on in the sixteenth century A.D. scarcely a line of any importance had been added to his works on the structure and classification of plants. The names we now find on the records were of men who cannot be said to be "botanists" in the sense in which we now interpret the word ; it would be more correct to call them "herbalists," for their primary interest in the subject was not botanical but pharmaceutical. Among ... –1534), Fuchs (1501– ... (1515–44), the last- ... roaching the subject ... Athenian His early ... s a blow to botany from which it did not recover for a couple of generations.

Aristotle, it may be remembered, wrote a lengthy treatise on animals, and so may be regarded as the founder of the other biological science, zoology, but he also foun

no successor until the appearance of CONRAD GESNER (1516–65), who, after a poverty-stricken youth, rose to be professor of natural history in the university of Zürich. He produced a *History of Animals* in five volumes, in which he attempted to give an account of every animal then known. His work on the sister science of botany, which he never completed, was a morphological treatise on flowers, fruits and seeds. In this book he shows that he had pondered over the problem that was destined, some three hundred years later, to exercise the brains of biologists, viz. the signification of the terms "species" and "genus."

Lastly, it was during the latter half of the sixteenth century that university botanic gardens began to be established, and first of all in Italy. That of Padua was founded in 1545, of Pisa in 1547, and of Bologna in 1567, while later in the century other countries followed suit, *e.g.* at Leyden in 1577, Leipzig in 1580 and Montpellier in 1596. The first university garden to be created in Britain was that of Oxford, which dates from 1621.

Earlier in this chapter we learnt something of the revolution in thought that followed the publication of Copernicus's great generalization that the sun was the centre of the solar system and not the earth, and that the planets, including the earth, revolved round it. It was not to be expected that such an upset of all preconceived ideas should be accepted at once as self-evident even by the astronomers. The hold of tradition and authority was too strong for many of them. One of these was TYCHO BRAHÉ, the first practical astronomer.

Tycho was born in 1546, the son of a Danish nobleman. He was adopted by an uncle, who gave him a good education and sent him, at the early age of thirteen, to the university of Copenhagen. On August 21, 1560, there occurred an eclipse of the sun, which had been predicted to take place on that day. It was not so much the eclipse itself as the accuracy of its prediction that stimulated the boy of fourteen to learn what he could of the science that

held in it such tremendous possibilities. Law, to which he was next apprenticed, had no charm for him, and instead

TYCHO BRAHE.
(From an old print; original unknown.)

of assiduously conning the mysteries of conveyancing and general legal procedure, he spent his money on the purchase

of the *De Revolutionibus* of Copernicus, and of such astronomical instruments as were then available, and his time in studying the movements of the heavenly bodies from his bedroom window. He soon discovered that the tables that had been compiled by his predecessors were extremely inaccurate, and that the instruments were so crude that it was impossible to obtain any reliable data by their use, and so he determined to prepare a new set of astronomical tables, and vowed to devote his life to the task.

In 1565 his uncle died and, by his will, left Tycho his heir. Freed thus from all financial worries as to his future he gave up the study of law and returned to his native land, where, however, he received such scant encouragement in his new pursuits that he returned to Germany and settled first at Wittenberg and afterwards at Rostock. A rather amusing story is told of him, that on one occasion he held a heated argument with a comrade on some mathematical problem, with the result that the disputants came to blows which in the end took the form of a duel to be held at 7 p.m. on a December evening—scarcely the time of day and year to favour skilful manipulation of rapiers. Honour was finally satisfied by his opponent slicing off Tycho's nose! Tycho, who had shown himself to be a clever instrument-maker, manufactured himself a new nose which he wore for the rest of his life, carrying about with him a pot of cement to refasten the pseudo-member whenever his impetuous nature disturbed it from its moorings.

Soon afterwards he removed to Augsburg, where he constructed his famous quadrant, an instrument of such massive proportions that it took the united strength of twenty men to carry it to and erect it in his garden. It was with this instrument that he made his first observations. In 1571 he returned once more to Denmark, and in order to obtain funds sufficient to provide himself with additional instruments, he took to the study of alchemy and the manufacture of patent medicines, one of which had a great reputation as a panacea for all diseases. He was also invited to deliver a course of lectures at the university

which, after some hesitation, he did. Finally the king, Frederick II., offered him a site for an observatory, £20,000 towards the cost of its erection, and an income of £400 a year for life if he would settle in Denmark and give his nat[illegible] [illegible]xpected to [illegible] [illegible] to say, Ty[illegible] fixed on the island of Hven, lying in the Sound, between Zealand and Sweden, the southern part of which at that time belonged to Denmark. On Hven was built a magnificent observatory, fully equipped with everything that could be devised for the prosecution of the science of astronomy. The name of this scientific palace was Uraniborg, or the temple or castle of the heavens. Here Tycho lived and laboured for over twenty years, until his friend and patron, King Frederick, died. The new king, an ignorant and arrogant boy, doubtless egged on by the bigwigs who, on their visits to Uraniborg, had been snubbed by the somewhat radical and autocratic astronomer, confiscated his estate and stopped his salary One of Tycho's visitors had been King James VI of Scotland, afterwards James I. of England, who had resided for over a week at Uraniborg, and this monarch presented him with a valuable dog. One day the chancellor of Denmark apparently ill-treated the poor beast, conduct which caused Tycho to reprimand the chancellor in terms that that statesman highly resented. When Tycho fell on evil days the chancellor took his revenge by appointing a commission to inquire as to the value of Tycho's work, and this body, probably selected *ad hoc*, reported that in its opinion the work was not only useless but even objectionable Then trouble began; Tycho was driven to leave the country, and it was not until two years had elapsed that the Emperor Rudolph of Bohemia, in 1599, invited him to Prague to carry on his labours there, allotting him an observatory, a house and a pension. Here he continued his compilation of the tables he had placed before himself as his life work, and

where he had the supreme good fortune of having as his pupil and assistant one destined to become an even greater man than himself—Johannes Kepler.

Of the great observatory at Hven nothing now remains but a heap of earth; of the array of instruments, one globe only is preserved in the Academy of Science at Copenhagen. *Sic transit gloria mundi.* Of Tycho himself, as an everlasting memorial, stand the famous Rudolphine Tables, completed by Kepler after his master's death—tables which, as we shall see, formed the basis on which the invaluable Nautical Almanacks of the present day are constructed.

"As a practical astronomer Tycho has not been surpassed by any observer of ancient or modern times," says one of our great physicists, Sir David Brewster. "The splendour and number of his instruments, the ingenuity which he exhibited in inventing new ones and in improving and adding to those which were formerly known, and his skill and assiduity as an observer, have given a character to his labours and a value to his observations which will be appreciated to the latest posterity."

Tycho's last recorded words were, "*Ne frustra vixisse videar*"—"Oh that it may not appear that I have lived in vain!" An encomium like that of Brewster is the answer to his lament, and it is an answer that will be confirmed by the testimony of every physicist and astronomer since his day.

CHAPTER V

THE THREE IMMORTALS: KEPLER (1571–1630), GALILEO (1564–1642), NEWTON (1642–1727)

IF men of science, more especially those that have devoted their lives to the study of mathematics, astronomy and physics, were asked to name the three greatest investigators of natural phenomena in the centuries immediately succeeding what is somewhat vaguely spoken of as the Renaissance, there can be little doubt that they would select Kepler, Galileo and Newton—a German, an Italian and an Englishman. Science has no nationality, but all would agree in awarding to Newton the first place in order of merit. "Newton was the greatest genius that ever existed," wrote Lagrange, the famous French mathematician, "and the most fortunate, for we cannot find more than once a system of the world to establish." Yet Newton himself said, "If I have seen farther than Descartes, it is by standing on the shoulders of giants"

One of these giants was JOHANN KEPLER, the son of a well-born but shiftless adventurer-father and an ignorant and ill-tempered mother. The father lost what little patrimony he possessed and became an inn-keeper, while Johann acted as his pot-boy before he was in his teens. When only four years old he suffered severely from that fearful disease smallpox, the special scourge of Europe till Jenner introduced vaccination two and a half centuries later. This malady left Johann a weak, sickly youngster, with feeble eyesight—not likely, one would imagine, to gather strength of body or vitality of mind in the atmosphere of

where he had the supreme good fortune of having as his pupil and assistant one destined to become an even greater man than himself—Johannes Kepler.

Of the great observatory at Hven nothing now remains but a heap of earth; of the array of instruments, one globe only is preserved in the Academy of Science at Copenhagen. *Sic transit gloria mundi.* Of Tycho himself, as an everlasting memorial, stand the famous Rudolphine Tables, completed by Kepler after his master's death—tables which, as we shall see, formed the basis on which the invaluable Nautical Almanacks of the present day are constructed.

"As a practical astronomer Tycho has not been surpassed by any observer of ancient or modern times," says one of our great physicists, Sir David Brewster. "The splendour and number of his instruments, the ingenuity which he exhibited in inventing new ones and in improving and adding to those which were formerly known, and his skill and assiduity as an observer, have given a character to his labours and a value to his observations which will be appreciated to the latest posterity."

Tycho's last recorded words were, "*Ne frustra vixisse videar*"—"Oh that it may not appear that I have lived in vain!" An encomium like that of Brewster is the answer to his lament, and it is an answer that will be confirmed by the testimony of every physicist and astronomer since his day.

CHAPTER V

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a fifth-rate public-house and in a miserable home where the perpetual squabbles of the family must have been a heavy handicap [illegible]'s unhappy childhood was sp[illegible] the duchy of Wurtemberg, [illegible] thousand people, where Johann was born just after Christmas Day in the year 1571.

Where and how he acquired his elementary education we do not know. By the time he had reached the age of seventeen his father had deserted his wife and family, and his mother, having no husband to nag, expended her evil temper on her relatives and friends. It was soon obvious that Johann was never likely to earn a living in any trade demanding physical strength, but there was no question about his possessing very considerable mental powers, and so the family advisers decided that he must be trained for almost the only profession open in those days to "a lad o' pairts," viz. the Church; and so, in his seventeenth year, he entered the university of Tübingen, where he studied classics and divinity to qualify himself for his prospective career Incidentally, however, he seems to have devoted considerable attention to mathematics and astronomy, more especially to the works of his great predecessor, Copernik. In these latter studies he attained such eminence that he was persuaded to give up his theological work and, in 1594, when he was only twenty-three years old, to accept the professorship of astronomy in the university of Grätz, or Graz, in Styria. At this centre of learning, it is true, he did teach astronomy, as we now understand the term; but the science, in Kepler's time, was more than half astrology, and he had to spend much of his leisure working out horoscopes as a livelihood. "Mother Astronomy," he wrote, "would surely have to suffer hunger if the daughter Astrology did not earn their bread"

Kepler was a Protestant, and the university was also Protestant; but presently the ruling powers decided that it must become Catholic, and thereupon all the Protestant

professors were expelled. Kepler alone, later on, was recalled, but when he returned he found himself without any students to teach.

While at Graz Kepler was a firm believer in the influence of the celestial bodies on human affairs, and during an intensive study of astrology he came across the views of the ancient geometricians on what were believed to be the five fundamental solids, viz. the tetrahedron, cube, octahedron, dodecahedron and icosahedron, with four, six, eight, twelve and twenty sides respectively. At that time only five planets were known to exist in the solar system, viz. Mercury, Venus, Mars, Jupiter and Saturn, and Kepler eagerly seized on the idea of a relationship between these five solids and the five planetal orbits. He took the earth's orbit as a sphere and round it he framed a dodecahedron. This figure he enclosed in another sphere, which he regarded as the orbit of Mars. Round the Martian sphere he arranged a tetrahedron, whose corners plotted out the spherical orbit of Jupiter. Then followed the cube, enclosing the orbit of Jupiter, which gave eight points on the orbit of Saturn. Inside the earth's sphere he placed an icosahedron, enclosing yet a smaller sphere, which was the orbit of Venus; and, finally, an octahedron, which bounded the orbit of Mercury.

Of course this fanciful cosmogony was a mere will-o'-the-wisp, leading nowhere, for it was based on a false Aristotelian premise, viz. that the heavenly bodies moved in circles, since circular motion was believed to be the only perfect one. Further, Kepler was of course ignorant of the fact that there were more than five planets within the solar system, for it was not until two hundred years had elapsed that Herschel discovered Uranus, and more than another half century before Adams and Leverrier added Neptune to the list.

His own work, however, showed him, very soon afterwards, that he had been chasing a chimera. The solid-sphere hypothesis led to one momentous result, for through it, in 1596, Kepler became acquainted with the great Danish

astronomer, Tycho Brahé, and through him, in turn, with the even greater Galileo.

Finding the means of living increasingly difficult to obtain, Kepler left Graz in 1600 to become assistant to Tycho Brahé, who was then resident in Prague under the patronage of the Emperor Rudolph II. Although fallen from his high estate as a Danish nobleman and director of the famous observatory of Uraniborg, Tycho was still a comparatively wealthy man, and enjoyed considerable influence at the emperor's court. He not only aided Kepler financially, but gave him free access to the great series of tables he had compiled for the purpose of determining the positions of the moon, the planets and the so-called fixed stars in the heavens. In 1601 Tycho died, and on his deathbed bequeathed to Kepler the task of editing and completing these records known afterwards as the Rudolphine Tables in honour of the emperor, the precursors, as we have said, of our well-known Nautical Almanack. Kepler had thus an immense accumulation of data on which to work, and from their study he evolved, during the next ten years, the three fundamental laws of planetary motion that formed the basis of all future investigations of the heavens, and made possible the *Principia* of Newton.

When Tycho died the emperor appointed Kepler to succeed him, and thus, for a number of years at least, he had the use of Tycho's astronomical instruments and the Rudolphine Tables, which he had promised Tycho to complete and publish. Strange to say, Tycho never accepted Copernik's system, and still held that the earth was the centre of the universe, round which all the celestial bodies revolved. Kepler, on the other hand, believed the sun to be the centre of the system, although it was hardly likely that he subscribed to the popular notion that the planets were guided in their paths by angelic agency!

Some eight years after Tycho's death, Kepler made his first great discovery. With the aid of his master's tables he worked out afresh the orbit of Mars, and from the

data he had at his disposal calculated the various positions the planet should occupy, assuming that it travelled in a circle. Basing his calculations on this erroneous hypothesis he found that his own results did not agree with Tycho's figures; Mars was not where it should be. Disappointed, but not discouraged, he tried again, wisely saying that "all *theories* must be wrong if they did not agree with Tycho's *facts*." After many attempts he found that an oval orbit, though not a perfect solution, was more closely in conformity with the data than a circular one. At length he hit on the ellipse, which satisfied the conditions perfectly. He might well have copied Archimedes, and shouted "Eureka" through the streets of Prague!

He then enunciated the first of his famous Laws:

> Planets move in ellipses with the sun in one of the foci of the ellipse.

The great Greek philosopher on whose supreme authority learned men had based their faith for nearly two thousand years was thus entirely wrong, for, so far as the planets were concerned, circular motion was neither perfect nor natural.

But he did more than this. From the tables giving the positions of Mars he saw that that planet moved more rapidly when it was close to the sun and more slowly when it was farthest away. After a prodigious amount of calculation he arrived at results which he embodied in his second Law:

> The imaginary line joining the sun and the planet—called in geometrical language the radius vector—sweeps over equal areas in the ellipse in equal times.

Thus the first two fundamental principles on which the motions of the heavenly bodies are based were found at last. There was yet a third principle that awaited recognition, but that came later.

In 1612 his patron, the Emperor Rudolph, died, and from then onwards one misfortune after another seemed to dog his footsteps. His wife fell ill and died; his three children all sickened, and one of them died of smallpox, the same

dread disease from which he himself had suffered so grievously in his childhood. He was hard pressed for money even to buy daily bread. At last, despairing of making a living in Prague, he took up a teaching post in the Austrian town of Linz, where he supported himself and his two remaining children by writing astrological pamphlets like our familiar "Old Moore's Almanack." His aged mother, far away in Würtemberg, got into trouble with the courts over a lawsuit, and was finally arraigned for sorcery and condemned to torture. From that fate her son barely managed to save her, but not from prison. Release from the clutches of the law, a year later, was followed by a permanent release, for the poor old lady, after a stormy life, died at the age of eighty.

During all these troublous times Kepler still continued his efforts to find some connection between a planet's mean distance from the sun and the time it took to revolve round it. He soon discovered that the relation could not be a direct one; time and distance could not be directly proportional to each other. At last he found the answer to the riddle, and this he expressed in his third Law:

> The square of the time of the revolution of each planet is proportional to the cube of its mean distance from the sun.

One can well excuse his naïve self-congratulation at his success at the discovery of these three fundamental Laws, a success that fully justified the title afterwards given to him—"The Legislator of the Heavens." "Give me a place to stand on and I will move the world," said Archimedes, when demonstrating the principle of the lever; Tycho Brahé gave Kepler a place to stand on and if he *did* not actually move the world, he at least showed how the world moved. "It is not eighteen months," he wrote, "since I got the first glimpse of [illegible] very few days since the [illegible] gaze upon, burst upon m[illegible] dulge my sacred fury. I will triumph over mankind by the honest confession that I have stolen the golden vases of the Egyptians to build a tabernacle for my God far away

from the confines of Egypt. If you fo:
if you are angry, I can bear it ; the dic
written, to be read either now or by p
which ; it may well wait a century for a
prophecy, for Newton was born twelve
died—"as God has waited six thou
observer."

But the end was fast approaching.
published which might be called a popu
doctrines of Copernik, in which he in
discoveries. This volume received th
with Copernik's *De Revolutionibus Or*
being placed on the Index Librorum Pr
who would not see, than whom there
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suppressed. The Rudolphine Tables
in 1627, partly at the Government's
Kepler's own, although how he manage
has never been disclosed.

Shattered in health and feeble of bo
of adequate nourishment, broken in s
ending monetary troubles and official
last effort to obtain the large arrears st
labours in Prague, and journeyed to th
cause in person—but all in vain. He c
redress, and, embittered by failure an
poor philosopher fell ill of brain feve
in Bavaria, where he lies buried.

Over a century ago a movem
a monument to his honour, but
as one of his biographers (Si
matters little one way or t
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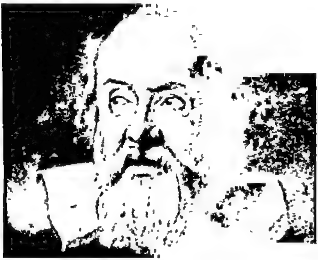
century and a half after h
Milton wrote of Shakespeai

> "What need'st thou s
> Thou, in our wond
> Hast built thysel

If Kepler stands out pre-eminently as a mathematician, his contemporary, Galileo, ranks with Archimedes as one of the most brilliant experimental philosophers the world has ever seen. GALILEO GALILEI, to give him his full name, was born in Pisa, the scene of one of his earliest triumphs,



GALILEO.
(From the painting by Sustermanns in the Uffizi Gallery, Florence.)

in 1564, seven years before Kepler began his chequered existence. He came of a noble but impecunious family, and at an early age gave evidence of great intellectual ability and a genius for mechanical invention. But the financial condition of his family rendered it essential that young Galileo should be apprenticed to some trade, and his father chose for him that of a cloth merchant. Some preliminary education was necessary, however, even for that career,

and Galileo consequently was sent to school at the Benedictine Monastery of Vallombrosa, near Florence, where he studied classics, but showed also marked talent in music and painting. At the age of eighteen he went to the university of his native town to study medicine, and there he came under the distinguished botanist, Cesalpino. Natural history, however, failed to detach him from his first love—mathematics and mechanics. It is recorded of him that, while supposed to be deeply immersed in the study of the works of Galen and Hippocrates, he kept hidden beneath these tomes the treatises of Euclid and Archimedes, which he perused whenever opportunity offered. Seeing that his son would never become a medical man with any love for his profession, his father at length gave way and allowed the lad to follow his natural bent.

Galileo's first contribution to science resulted from an observation he made while attending service in the cathedral at Pisa. A sacristan, after lighting one of the pendent lamps, left it swinging, and Galileo thereupon proceeded to time the oscillations by his pulse, for this was before the days of watches, which did not come into general use until after the middle of the seventeenth century. At first the lamp swung wide, but the oscillations gradually diminished in extent, and yet Galileo noticed that the time taken for the widest swing was exactly the same as that taken for the smallest. This led him to the idea of the isochronism of the pendulum, and to the principle of the modern clock, which he conceived might be of great value to the physician as an accurate method of registering the pulse beat. But his experiments in adapting this idea to the actual construction of the instrument taught him that the period of the oscillation varied with the length of the pendulum, and, after some calculation, he established the law that the time of oscillation varied with the square root of the length of the pendulum. This law we all unconsciously recognize every time we screw up the disc below the bulb when the clock is found to be going too slow and screw it down when the clock is gaining.

Free now to follow his guiding stars, mathematics and

mechanics, Galileo progressed with enormous strides, so rapidly indeed that he emulated Kepler by becoming professor of mathematics at the university of Pisa before he was twenty-six years old, earning the princely salary of £13 per annum or 8½d. per day! During his tenure of the chair he studied the laws of falling bodies, and discovered that the velocity of a weight falling down a slope was independent of the angle of the slope, and that the height through which the weight fell was proportional to the square of the time it took to fall.

To us, in these days, it is ever a matter of astonishment how firmly men pinned their faith on the *ipse dixit* of Aristotle—"The master hath said it," and therefore it must be true. At Oxford, at the time of Bruno's visit (1583), "the university statutes enacted that bachelors and masters who did not follow Aristotle faithfully were liable to a fine of five shillings for every point of divergence, and for every fault committed against the logic of the *Organon*." At Pisa also the doctrines of Aristotle were
offend against them was
were regarded as the
ge; students were compelled to commit his sayings to memory, and any expression of doubt as to their truth was looked upon as a piece of gross impertinence, if not actually as a crime. But just as Kepler had dared to show that a planet's orbit was not a circle, as Aristotle had laid down, but an ellipse, so Galileo also challenged the sayings of the great Greek on the subject of mechanics. Aristotle held that bodies fell to earth at rates proportional to their respective weights. Thus a 100 lb. weight fell 100 times as fast as a 1 lb. weight, but Galileo asserted that weight had nothing to do with the case, and that, in a vacuum, all bodies fell at the same rate and would do so in air were it not for the resistance of the medium through which they fell. This, of course, was rank heresy! The Church, governed by its rigid dogmas, and the Schools, equally rigid in their belief in the infallibility of Aristotle, alike condemned him. But Galileo was not to be brow-

beaten. He challenged them both to a demonstration of the truth of his assertion, and then followed a dramatic experiment on the Leaning Tower. This famous campanile rises to the height of 179 feet in eight colonnaded stories, and is $16\frac{1}{2}$ feet out of the perpendicular, inclining towards the south. In the presence of his fellow-professors and a crowd of curious onlookers, Galileo climbed to the topmost balcony and dropped, at the same moment, two weights, one of 100 lb. and one of 1 lb. One can imagine the suppressed excitement with which the fall of the two bodies was watched. Would the heavier weight strike the ground first, as Aristotle had declared, or——? A moment would answer the question, and it did. Both weights clanged on the pavement at the same instant. As one writer has put it, that simultaneous clang was the death-knell of dogmatic authority—if only the learned pundits of Pisa but knew it! Gone for ever in the minds of all thinking men was the belief in Aristotelian infallibility that had held science in bondage for nearly twenty centuries! Did the experiment bring instant conviction of the truth to the biased minds of the Pisan professoriate? Not a bit of it. "Opinio veritate major," said the matter-of-fact Roman, Cicero, some seventeen centuries before, and Samuel Butler, the author of *Hudibras*, expressed the situation admirably when he wrote, soon after the date of Galileo's experiment:

> "And obstinacy's ne'er so stiff
> As when 'tis in a wrong belief."

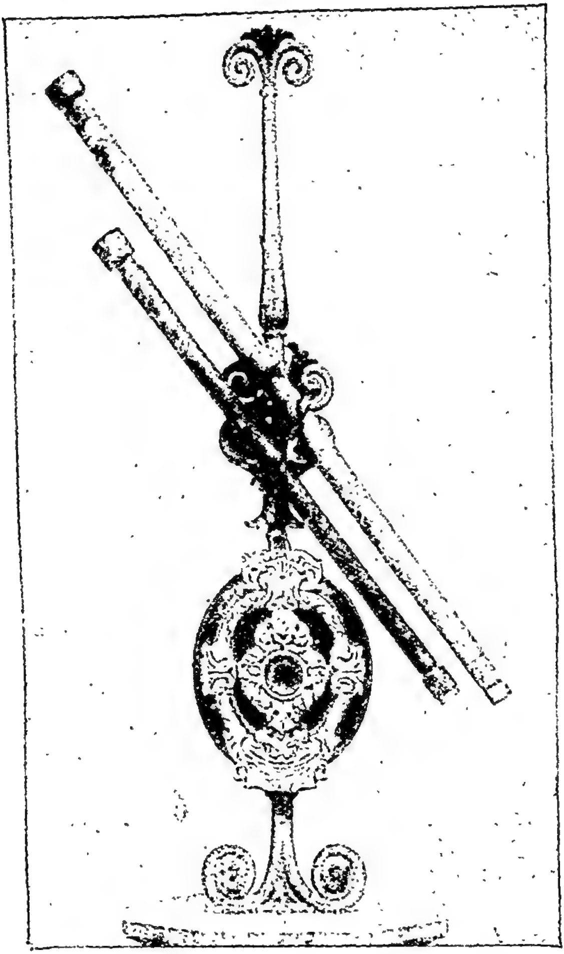
Tuscany was a papal state, and within its borders thought was not free, but freedom of thought is the salt of life. Venice, on the other hand, was a free republic and hostile to the papacy, and so Galileo shook the dust of Pisa off his feet and became professor of mathematics at the university of Padua, where he remained for eighteen years, and where all his best work was done. That he was a successful teacher in his new environment is shown by the fact that at one time he had as many as two thousand students under him. One of his first achievements at Padua was the

manufacture of a thermometer. It consisted simply of a tube terminating in a bulb and standing on end in a basin of water. The bulb was full of air, and an application of heat to the bulb caused the water to sink in the tube. The apparatus was not of much value, but it paved the way for the mercurial thermometer with a vacuum within a hermetically sealed tube, which was invented some seventy years later.

By this time Galileo had completely adopted Copernik's theory of the heavens, and taught his students that the earth was not the centre of the universe, but that it was relatively a mere speck in the solar system, and that men and women were infinitesimal particles crawling over its surface. This teaching was a terrible blow to the orthodox, but Galileo boldly proclaimed the truth in his native tongue and not in monkish Latin, so that every one could understand, confident of his safety in a free city, where Rome and its terrible Inquisition could not harm him

Meanwhile, in 1608 in far-off Middelburg in Holland an unknown spectacle-maker called Lippershey, it is said by accident, placed two lenses one behind the other in such a way that he was able to see the weathercock of a church spire much more clearly and of larger size than he could with the naked eye. Galileo heard of this, and wrote to his brother-in-law on the subject.

"You must know, then," he says, "that two months ago there was a report spread here that in Flanders some one had presented to Count Maurice of Nassau a glass manufactured in such a way as to make distant objects appear very near, so that a man at a distance of two miles could be clearly seen. This seemed to me so marvellous that I began to think about it. As it appeared to me to have a foundation in the Theory of Perspective, I set about contriving how to make it, and at length I found out, and have succeeded so well that the one I have made is far superior to the Dutch telescope. It was reported in Venice that I had made one, and a week since I was commanded to show it to his Serenity and to all the members of the



TWO OF GALILEO'S TELESCOPES
(preserved in the Tribuna di Galileo at Florence).

A broken object glass, with which the four satellites of Jupiter were discovered, is mounted in the centre of the ivory frame.

senate, to their infinite amazement. Many gentlemen and senators, even the oldest, have ascended at various times the highest bell-towers in Venice to spy out ships at sea making sail for the mouth of the harbour, and have seen them clearly, though without my telescope they would have been invisible for more than two hours. The effect of this instrument is to show an object at a distance of, say, fifty miles, as if it were but five miles."

He was promptly rewarded by the Signory confirming him in his professorship for life and by doubling the salary he had previously enjoyed. Had he only remained in Padua he might have escaped the sad fate that was in store for him, and his enemies would have been spared the brand of everlasting shame attached to their names.

But it was not to watch the far-distant galleys of Antonio bearing the merchandise of many nations up the Adriatic to the quays of Venice that Galileo made his telescope, a feeble instrument in our eyes, that magnified only thirty times; he turned it first on the moon and saw it pitted with the craters of bygone volcanoes, and showed to wondering friends its mountains, its ravines and plains. He announced that it shone by light reflected from the sun and had no light of its own, and, further, that a lunar inhabitant, if such a person could be imagined, would see the earth, not as a dark mass but also as a luminous sphere and for the same reason, but even brighter because of its enveloping atmosphere. He cared nothing for the angry outcries of the Aristotelians, who accused him of defiling the pure smooth surface of the moon by turning his telescope upon it, although his contempt was not forgotten against him by his enemies in years to come.

Wherever he turned his glass new stars appeared out of the dark abyss of heaven, and he recognised them as pin-points of light, and not as discs like the planets. He studied the phases of the moon, and distinguished similar phases in Venus and Mercury. The wonderful Milky Way, that "meeting of gentle lights without a name" as his contemporary, Sir John Suckling, described it, he announced was

composed of star dust, as Democritus had guessed two thousand years before. He discovered spots on the sun—another insult to the greatest of the celestial bodies—and, after watching their changes in position, said that the sun rotated on his axis once a month. He found that Jupiter had four satellites (we know of eight nowadays) that revolved round him as our own moon revolves round the earth. The pundits refused to believe this, and some even went so far as to decline to look through his telescope, lest they should see these moons. The story goes that one of these unbelievers died soon afterwards, when Galileo sarcastically remarked, "Well, I hope he saw them on his way to heaven." The planet Saturn puzzled him sorely, for he said it had a triple state. The lateral protuberances were, of course, the optical expression of the well-known "rings," but his telescope was incapable of resolving it. That resolution had to wait for Huyghens, sixty years later.

It was now that the dark shadow began to fall on him. At Padua he wrote, "I have no hope of returning to my own country," but that hope was after all fulfilled when the Grand Duke of Tuscany offered him the post of "Ducal Mathematician and Philosopher" at Florence. Now at last came to the theologians the opportunity for which they had been waiting. What it was safe to say in Padua under the enlightened rule of the Doge, was anything but safe within the territory of the Pope. In 1615 Copernik's great work, *De Revolutionibus*, was placed on the Index, and since Galileo had pronounced his adhesion to the principles it taught he came under grave suspicion of heresy. The story of his declining years, darkened by the persecution of the Inquisition, has been told so often, and the story is in itself so shameful a reflection on those who might at least have left the old philosopher severely alone, seeing that he was and had always been a devout Catholic, that the briefest summary is all that seems necessary here.

In 1616 he was haled to Rome and there warned that he must neither teach nor defend the pernicious doctrines that the sun was immovable and that the earth moved round

it, since these were contrary to Holy Scripture. Galileo, after expending all his eloquence and logical acumen in support of his beliefs, was forced to submit, and to return to Florence, where he lived quietly for seven years. When a new Pope, who, as a cardinal, had been a friend of Galileo, was elected to the chair of St. Peter, he went to Rome to congratulate him, and if possible to induce his Holiness to rescind the edict of 1616, but without success, although the Pope received him apparently with every protestation of friendship.

Perhaps over-encouraged by his reception, he returned to Florence and, in 1632, foolishly wrote *A Dialogue of the Two Systems of the World*, in which the relative merits of the Ptolemaic and the Copernican systems were discussed by "Simplicio," who represented the Aristotelian view, and "Salviati," who was made to support the Copernican, with a go-between, "Sagredo," who was the critic and clown of the debate. Unfortunately the Pope was persuaded to believe that "Simplicio," who was made to propound all the absurdities of the orthodox argument current at the time, was really intended to be himself, and that in the pamphlet Galileo was holding him up to ridicule.

Again Galileo was summoned to Rome, where he was brought before the Inquisition. This time he was treated with much greater severity, and was made to recant all his views on bended knees before the assembled cardinals. "I am in your hands," said the poor old man plaintively; "I will say whatever you wish." His recantation was read publicly in every church, cathedral and university in the country, to the grief and dismay of his many friends and pupils. The story of his having risen from his knees muttering, "But it moves all the same," is purely apocryphal, for the tribunal sat with closed doors, and none of those present were in the least likely to repeat the whisper even if it had been made, nor would it have had any other effect than to have increased Galileo's punishment, even if it did not bring upon him the fate of Giordano Bruno, who was burnt at the stake in 1660 for a similar heresy.

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In 1616 he was haled to Rome and there warned that he must neither teach nor defend the pernicious doctrines that the sun was immovable and that the earth moved round

it, since these were contrary to Holy Scripture. Galileo, after expending all his eloquence and logical acumen in support of his beliefs, was forced to submit, and to return to Florence, where he lived quietly for seven years. When a new Pope, who, as a cardinal, had been a friend of Galileo, was elected to the chair of St. Peter, he went to Rome to congratulate him, and if possible to induce his Holiness to rescind the edict of 1616, but without success, although the Pope received him apparently with every protestation of friendship.

Perhaps over-encouraged by his reception, he returned to Florence and, in 1632, foolishly wrote *A Dialogue of the Two Systems of the World*, in which the relative merits of the Ptolemaic and the Copernican systems were discussed by "Simplicio," who represented the Aristotelian view, and "Salviati," who was made to support the Copernican, with a go-between, "Sagredo," who was the critic and clown of the debate. Unfortunately the Pope was persuaded to believe that "Simplicio," who was made to propound all the absurdities of the orthodox argument current at the time, was really intended to be himself, and that in the pamphlet Galileo was holding him up to ridicule

Again Galileo was summoned to Rome, where he was brought before the Inquisition. This time he was treated with much greater severity, and was made to recant all his views on bended knees before the assembled cardinals. "I am in your hands," said the poor old man plaintively; "I will say whatever you wish." His recantation was read publicly in every church, cathedral and university in the country, to the grief and dismay of his many friends and pupils. The story of his having risen from his knees muttering, "But it moves all the same," is purely apocryphal, for the tribunal sat with closed doors, and none of those present were in the least likely to repeat the whisper even if it had been made, nor would it have had any other effect than to have increased Galileo's punishment, even if it did not bring upon him the fate of Giordano Bruno, who was burnt at the stake in 1660 for a similar heresy.

There is even considerable doubt as to whether Galileo was actually tortured physically—one hopes the doubt is justified—but what must the mental torture have been to a man of his age (he was now seventy), compelled to abjure all that he had taught for the past forty years and sincerely believed to be true? His punishment was severe enough in all conscience, for in addition to the recantation, he was condemned to imprisonment for life, and to recite the seven penitential psalms once a week for three years. This decree—"a blasphemous record of intolerance and bigoted folly"—was signed by seven cardinals out of ten. All honour to the three who refused to sign!

Some time afterwards he was permitted to live first in Siena and then in Florence, but in strict seclusion, no one being allowed to visit him, lest conversation with his visitors might help to spread his doctrines abroad. To add to his trials he became blind, and it is on record that another great man, also fated to lose his sight, the poet Milton, at that time a young man of twenty-nine, did visit him, but of the conversation that took place between them there is no record. "Alas!" Galileo wrote to his friend Diodati, "your dear friend and servant, Galileo, has been for the last month totally blind. This earth, this heaven, this universe which I by my wonderful discoveries and demonstrations have enlarged a hundred thousand times beyond the conception of the wise men of bygone ages, henceforth is shrunk for me into the narrow space which I myself fill in it. So it pleaseth God; it shall therefore please me also."

During these last few years, when he was no longer able to gaze through his telescope at the mysteries of the heavens, he devoted himself to meditations on the laws of motion, by no means the least of his great achievements. Although most of his manuscripts were destroyed, it is said, by his son, who hoped thereby to obtain merit in the world to come, the treatise on the mechanics of motion was preserved by his pupil, Torricelli. What Galileo discovered really formed the foundation of Newton's far greater work many years afterwards.

If a moving body be acted upon by no force of any kind, wrote Galileo, it follows that it will continue to move uniformly not only in the direction in which it is moving, but also at the same rate; but if it curves out of that path, then some force must have acted upon it. Again, when such a force acts on a moving body, the motion changes in speed or direction or both, in degree proportional to that force and in the same direction as that in which the force acts. The planets change their direction, but not their rate of motion, and hence the only force required is a centripetal one deflecting their pathways inwards towards the sun, and this centripetal force must be equal to the centrifugal one that resists the inward pull. Action and reaction are equal and opposite.

These were the great fundamental laws that Galileo evolved in his dark hours, but, simple and familiar as they seem to us, they were the lights that pointed the way to the discovery of the laws of universal gravitation by an even mightier intellect born that very year in which he died in a village in far-away England.

Illness after illness fell on the weary old man, and at last, at the Villa Arcetri, near Florence, in his beloved Tuscany, on the 8th of January 1642, passed away

"The starry Galileo with his woes."

On Christmas Day of that same year there was born, in the Manor House of Woolsthorpe in Lincolnshire, an infant so puny that his mother said she "could put him in a quart mug." "Little bodies have great souls," says an old English proverb, and this one is peculiarly apposite to ISAAC NEWTON. If his mother could squeeze him into a quart mug, he certainly would not have taken a prize at a baby show, but every child knows what came out of a yellow pot that a fisherman once opened on a seashore. There arose a smoke that reached up to the clouds, that solidified into a genius greater than the largest giant. The story tells us how the unbelieving fisherman of the *Arabian*

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found the propositions so self-evident that he flung it aside as "a trifling book," and took to reading Descartes's *Geometry* instead. It was not long before he outstripped that famous mathematician by inventing the binomial theorem, and, later on, the differential calculus, although Leibnitz has a claim to its independent invention. His next exploit was to interpret the haloes that appeared round the moon before the oncome of stormy weather, and this phenomenon he attributed to the action of light on the water particles in the upper strata of the atmosphere. In all his studies he was cordially aided by Dr. Barrow, who was at that time Lucasian professor of mathematics at the university. In 1665 he took his B.A. degree.

In the same year the university was closed on account of the Great Plague, and Newton retired to Woolsthorpe, there to meditate on the revolutions of the planets round the sun. He was, of course, familiar with Kepler's Laws, but they did not tell him *why* the planets revolved, nor what kept them in their orbits. Why did they not fly off into space? He soon realized that the older theories did not meet the case, for they seemed to require some external force to keep them in their places. The integrity of the whole solar system must depend on some constant *force originating from the sun—a force that varied inversely* as the square of the distances of the revolving units from it. The question at once arose, was gravity sufficient? If so, the attractive power of gravity as regards objects near the earth must vary as the square of the distance of the object from the earth's centre. Newton then tackled the problem of the relations between the moon and the earth. The moon was calculated to be sixty earth's radii distant, and hence the attractive force of gravity at a distance as far off as the moon could be only $\frac{1}{3600}$ of what it was on the earth's surface. The problem then was how much does the moon fall towards the earth every second? The answer depended on the size of the earth. At that date each degree of the 360 of the earth's circumference was taken to be 60 miles, and on that assumption

Nights induced the genius to re-enter the pot, but nothing has ever been able to cramp the magnitude of the genius that might have emanated from the quart mug of Woolsthorpe.

Newton's father was a farmer who died before Isaac was born. His mother remarried some time afterwards and left the boy in charge of an uncle and aunt who had come to live at the Manor House. He was educated at first locally and then at the grammar school at Grantham, a few miles distant. He could not be said to be a model schoolboy in the sense of being an ardent student of the classics, but although he began badly he ended in being dux. Most of his spare time was spent in making mechanical toys and building dolls' houses for a little girl that lived in the house of a chemist in Grantham where he lodged. Newton never married, and rumour says that little Miss Storey was his one and only love.

When fifteen years of age he was taken from school to become a farmer, but even then, boy-like, he was not above playing tricks on the country-folk by tying paper lanterns to the tails of kites and persuading them into the belief that they were watching comets. In the great storm of 1658 he tested the force of the wind by trying how much farther he could jump with it than against it. He manufactured a water clock, and carved a sundial on a stone in the wall of the Manor House, a stone now reverently preserved in the rooms of the Royal Society. As a farmer he was a total failure, and, seeing that his bent lay towards books and not live-stock, his uncle wisely sent him back to school again, and thence in due course to Trinity College, Cambridge, where he occupied rooms near the gateway. Kepler and Galileo had no monuments erected to their memory, but Trinity was more generous and appreciative, for a statue now stands in the antechapel in honour of her most distinguished alumnus.

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the fall was not 16 feet per minute, as it ought to have been, but only 13.9 feet. It was not until sixteen years had elapsed that the source of the error was discovered. A degree on the earth's circumference was not 60 but 69.1 miles. But we are anticipating. Newton was puzzled, but not discouraged, and, as he says himself, he "laid aside at that time any further thought of the matter."

In 1669 Newton succeeded his old teacher, Barrow, as Lucasian professor of mathematics, at the early age of twenty-seven. His duties were to lecture once a week on some subject connected with mathematics, physics, or astronomy, and to devote two hours a week to tutorial work among his students. This left him ample time for research work on the subject he might select for his lectures. In the first year he lectured on optics, and in that department of physics he soon made startling discoveries.

In 1672 Newton was elected a Fellow of the Royal Society, and to signalize his election he promised the secretary that he would present to that learned body "a philosophical discovery, being in my judgment the oddest if not the most considerable detection which has hitherto been made into the operations of Nature."

It would appear that he was attempting to discover the cause of the blurred images given by lenses, with a view to their improvement, and during his investigations he came to the conclusion that the cause of the imperfection might reside not in the lens but in the light. When he allowed a pencil of light to enter a darkened room through a circular aperture in the window shutter, he naturally obtained a circular patch of light on the opposite wall; but when he placed a prism in the path of the ray, he found that in place of the circular disc he obtained a very much elongated ellipse, and that the light, instead of being white, showed itself as a coloured band giving the different hues of the rainbow, with violet at one end and red at the other, and, successively, indigo, blue, green, yellow, orange in varying shades in between. This rainbow effect had already been

observed by Descartes, but Newton went a step farther, and asked himself why the image should be elongated and not circular. After testing several hypotheses, he placed a second prism behind the first, only reversed, and found that he once more obtained a circular spot of white light. The second prism had neutralized the effect of the first. The idea then flashed upon him that white light was compounded of rays of different colour which, when passed through a prism, were bent out of their paths at different angles. To test this idea he introduced a second screen between the original prism and the wall, and adjusted it so that only one of the coloured rays passed through the hole. No dispersal took place, and he obtained a circular disc of red, yellow, blue, or other colour, according to the particular ray that he permitted to penetrate the aperture in the second screen.

The substance of his "oddest philosophical discovery" was, therefore, this: th[illegible] mixture of differently r[illegible] differed in colour, and th[illegible] always gave the same c[illegible] being red, those of mos[illegible] rays being intermediate [illegible] From this he made the [illegible] natural bodies had no colour in themselves, but that these bodies are variously qualified to reflect one sort of colour in greater amount than another—in other words, that by illuminating different bodies with pure coloured light they may be made to appear of any colour. This, of course, as every one knows, is the whole secret of a pantomime transformation scene.

This novel doctrine led to endless controversy, of which Newton got heartily sick. In a letter to the secretary of the Royal Society he said: "I see a man must either resolve to put out nothing new, or to become a slave to defend it." Newton was one of those great geniuses that cared nothing for what he got out of his discoveries either in the way of kudos or cash. Some of his most brilliant

inventions, like the reflecting sextant—the ship's quadrant known to and used by every ship's officer—were never published, the description of the sextant, for instance, being found among his papers after his death. Indeed, it may be said generally that the history of science shows that no discovery really worth while has ever been made by those who worked solely for the profit there was in it. In every instance the greatness of the discovery has been paralleled by the unselfishness of the discoverer. When Sir Humphry Davy was asked why he did not patent his miner's safety-lamp and earn his £5,000 or £10,000 a year, he replied: "I never thought of such a thing. My sole object was to serve the cause of humanity, and if I have succeeded I am amply rewarded in the gratifying reflection of having done so." "I could never work for money," said Pasteur, "but I would always work for science." Newton, when only twenty-seven, was asked to permit the publication of the solutions of certain problems that would have added greatly to his reputation, but he refused, adding, "I see not what there is desirable in public esteem were I able to acquire and maintain it. It would perhaps increase my acquaintance, the thing which I chiefly study to decline."

Having now elucidated the nature of light itself, Newton easily solved the problem of the blurred image, for it was obvious that each of the coloured rays on passing through a lens must have its own focus—the violet rays, being most refracted, having their focus nearest the lens, and the red rays, being least refracted, farthest away, so that an object placed too near the lens would have a white centre and a red-orange border, and, if too far, a white centre and a blue-violet border. The distance between the foci of the red and the violet rays he found to be about $\frac{1}{50}$ of the diameter of the lens, and this was termed the "chromatic aberration."

Although Newton never succeeded in making a truly achromatic lens for telescopic purposes, he got round the difficulty by the invention of the reflecting telescope.

Light was always reflected from a mirror in exactly the same way—the angle of incidence of the ray was the same as the angle of reflection. Newton then made a concave mirror from a mixture of copper and tin, the rays from which were concentrated at the focus of the mirror, and the image produced could be reflected from a small flat mirror to an eyepiece introduced laterally into the tube. Herschel, at a later date, tilted the concave mirror, and so rendered the small flat reflector unnecessary. Newton's first reflecting telescope may still be seen in the rooms of the Royal Society.

He also puzzled over the actual nature of light, and came to the conclusion that every object gave off invisible particles of matter which, impinging on the retina of the eye, produced the sensation of light. This, the so-called "corpuscular theory of light," held sway until it was replaced by a more satisfactory explanation, the "undulatory theory," put forward by Huyghens in 1678.

Meanwhile the researches of the French mathematician, Picart, had resulted in a new estimate of the size of the earth, after the determination of the exact value of a degree, viz. that it was not 60 miles but 69.1 miles. In 1682 Newton learned of this redetermination, and at once unearthed his old calculations that he had laid aside many years before and repeated them, using the new estimate of the earth's size as a basis. To his inexpressible joy the calculation came out right: the secret of the universe was revealed. It is said that he was so excited over his discovery that he forgot even to eat his meals. The story goes that a friend called on him on one occasion and, finding one place set for dinner and no Newton, he proceeded to eat the chicken and replaced the cover over the remnants. When at length Newton arrived he sat down to his meal, but, on lifting the cover, found only the bones. "Dear me," he remarked to his friend, "I thought I had not dined, but I see that I have." "Does Mr. Newton eat, drink, sleep like other men?" inquired a distinguished French mathematician "I picture him to myself as a

celestial genius, entirely removed from the restrictions of ordinary matter."

Appreciating the basal importance of Kepler's Laws, Newton was now able to propound Laws of his own, with gravity as the fundamental feature. Since a planet in its orbit round the sun describes equal areas in equal times, the attractive force must operate in a straight line between the sun and the planet. If the orbit be an ellipse, the attractive force must vary in intensity inversely as the square of the distance between the two bodies. Further, if there be a number of planets revolving round the sun, and if the materials of which they are made are equally affected by gravitation, "it can be demonstrated that the square of the periodic time in which each planet completes its orbit is proportional to the cube of the greatest diameter of that orbit."

It was a natural consequent of this discovery that not only did the sun attract the earth and the earth the moon, and vice versa, but that every body in the universe, however small, must attract every other body with a force directly proportional to the product of their masses and inversely to the square of the distance separating them. If two particles of whatever size are ten miles apart and attract each other with a certain force, that force is increased a hundredfold when they are brought within one mile of each other.

"The great Newtonian Induction of Universal Gravitation," writes Whewell, "is indisputably and incomparably the greatest scientific discovery ever made, whether we look at the advance which it involved, the extent of the truth disclosed, or the fundamental and satisfactory nature of this truth."

From the earliest times it had been observed that some relation existed between the tides and the moon. They were seen to be high when the moon was full or new, but why this should be so was not clearly understood until the universality of the Law of Gravitation gave the key to the riddle. It was then seen that both the sun and the moon attracted the mobile ocean, and that when both these

bodies exerted their attractive powers simultaneously, high or "spring" tides resulted, and "neap" (helpless) when the solar attraction on the sea and the lunar attraction were exerted at right angles to each other.

Another problem also was solved by the application of the same law. The earth moved, as Kepler had shown, in an elliptical orbit round the sun, and it might be concluded that the moon would similarly move in an elliptical orbit round the earth, with the earth in one of the foci of the ellipse, but this was discovered not to be the case. The moon's orbit was not a perfect ellipse, nor was the earth in one of its foci. The cause of these irregularities was, as Newton showed, the attraction of the sun for the moon, pulling it out of its proper course. Not only so, but other irregularities were seen to be due to the minor attractions of every one of the planets on every other in varying but lesser degree. Even the tilting of the earth's axis became explicable when it was realized that the moon had a greater attractive power on the more swollen equatorial region of the earth, and brought about the hitherto mysterious movements of the poles in space.

In consequence of the urgent pressure brought to bear on him by his friend Halley, afterwards Astronomer Royal, Newton gave permission for the publication of his discoveries, and in 1686 the manuscript of the *Philosophiæ Naturalis Principia Mathematica* was presented to the Royal Society and printed in the following year. Halley not only undertook the heavy task of seeing this memorable work through the press, but actually bore the cost of its publication. Very soon afterwards the volume was unattainable, and students were obliged to make manuscript copies for their own use.

The prodigious mental strain that Newton had undergone during his epoch-making researches had seriously affected his health, never robust at the best of times, and he suffered much from insomnia and nervous exhaustion. Mental rest was essentially required. In 1695 he was offered and accepted the post of Warden of the Mint, the

duties being light and the salary adequate, and two years later he was appointed Master, with an income of £1,200 to £1,500 per annum. He threw himself with characteristic energy into the recoinage then being carried out, and resigned his professorship and fellowship at Cambridge, so closing his long connection with the university city. In 1703 he was made President of the Royal Society, and in 1705 he was knighted.

In the last few years of his life he devoted himself to various matters far removed from those that had made his name famous all the world over—such as the prophecies of Daniel, alchemy and even hieroglyphics. At this period he suffered much from a painful disease known to medicine as phrenitis, and at last, worn out both in mind and body, he died on March 20, 1727, in his eighty-fifth year.

So passed the greatest scientific philosopher this country, or indeed any country, has ever produced. His discoveries were so vast and so far-reaching that people wondered if there was anything left to discover. The epitaph written by Pope for his tomb in Westminster Abbey well expresses this feeling:

"ISAACUS NEWTONUS
Quem Immortalem testantur Tempus, Natura, Cœlum.
Mortalem hoc marmor fatetur.

Nature and Nature's Laws lay hid in Night,
God said, Let Newton be! and all was Light."

Equally appropriate is the legend inscribed on the plinth of Roubiliac's statue of Newton at Trinity:

"Qui genus humanum ingenio superavit."

Newton's own estimate of his achievements was, however, characteristically humble:

"I know not what the world will think of my labours, but to myself it seems that I have been but as a child playing on the seashore; now finding some pebble rather more polished, and now some shell rather more agreeably variegated than another, while the immense ocean of Truth extended itself unexplored before me."

ISAAC NEWTON

(From the painting by J Vanderbank in the National Portrait Gallery)

CHAPTER VI

FROM ALCHEMY TO CHEMISTRY—THE PIONEERS

IT is extremely difficult for us, living in an age when many of the mysteries of Nature are commonplaces, to realize the condition of knowledge of chemistry three hundred years ago, when people still believed that there were only four elements—earth, water, air and fire; or three, if they accepted the alchemists' view—sulphur, mercury and salt. Nor can we help smiling at the grotesque conception of an intimate association between the sun, moon and planets and the common metals, for Chaucer tells us that—

> " Sol is gold, and Luna silver we threpe,
> Mars yren, Mercurie quiksilver we clepe,
> Saturnus leed, and Jupiter is tin,
> And Venus coper, by my fader kin "

Chemistry, in this primitive sense, arose among the Alexandrine Greeks early in the Christian era, for papyri dating from the third century have been found containing recipes for making alloys intended to facilitate the manufacture of false jewellery. The knowledge acquired in such tentative ways was passed on to the Arabs and by them to western Europe, but that knowledge was not co-ordinated, and, before it could become a science, theory had to be introduced to link the facts together, and this was the task of the first real chemists as distinct from the seekers after the philosopher's stone and the *elixir vitæ*, and even the medical chemists that followed Paracelsus.

One of the first of these pioneers was ROBERT BOYLE, a

son of the famous Earl of Cork. He was born at Lismore in the province of Munster in the year 1627, and died in London in 1691. He thus lived and worked during stirring times, and in an age that gave birth to some of England's most remarkable men, such as Newton, Wren, Locke, Hooke, Milton, Dryden, Bunyan and the diarists Pepys and Evelyn. He was educated at Eton, where he preferred study to games, and dabbled in all sorts of experiments, even in medicine.

After five years of residence and travel in France, Switzerland and Italy, he returned to England in 1644, and lived for a time with his favourite sister, Viscountess Ranelagh. In 1653 we find him studying anatomy in Dublin, where he saw " more of the variety and contrivances of Nature, and the majesty and wisdom of her Author, than all the books I ever read in my life could give me convincing notions of."

About the year 1645 " divers worthy persons, inquisitive into natural philosophy and other parts of human learning, and particularly of what hath been called the New Philosophy or Experimental Philosophy," began to meet from time to time to discuss such subjects, under the name of the " Invisible College," and of this club or society Boyle was a member. A few years later the society became divided into two sections, one of which had its station in Oxford, where Boyle had taken up his residence, while the other section met in London at Gresham College, often with serious inconvenience and even risk to its members owing to the disturbed conditions of the period.

At the Restoration the king was induced to take an interest in the proceedings of this little band of scientists, and in July 1662 gave it a charter of incorporation and presented it with a mace, which is placed on the president's table at every meeting to this day. Every one now knows of this body of workers under the name of the Royal Society of London. In 1669 Boyle removed from Oxford to London, and lived with his sister, Lady Ranelagh, for the next twenty-two years in a house in what is now Pall Mall.

Always more or less of an invalid owing to some kidney disorder, he lived a very retired life, although constantly visited by his scientific friends. In December 1691 his sister died, and Boyle, who was devotedly attached to her, felt the loss so acutely that he survived her only a week, and passed away on December 30, 1691.

After this brief sketch of Boyle's somewhat uneventful life, we may turn to the consideration of the work he accomplished for the advancement of science. He has been called the "Father of Chemistry," but it cannot be denied that he is best known as a physicist, and to his achievements in that connection we may first turn our attention. When only twenty-eight years of age he became acquainted with Robert Hooke, a most ingenious member of the "Invisible College," who ultimately occupied the post of experimenter to the Royal Society, as well as professor of geometry in Gresham College. Hooke's friendship with Boyle led to

barometer is constructed. Galileo had found that, on withdrawing air from a tube standing in water, the water rose in the tube to a height of about 34 feet, but that above that point it would not rise, and he rightly concluded that air had weight and pressed on the water surface outside the tube, forcing a column of water up it until it reached a height corresponding to the weight of the air pressing on the surface outside, viz. about 34 feet. Torricelli next employed mercury instead of water, and found that similarly the mercury rose in the tube to a height of about 30 inches, the smaller rise being accounted for by the fact that mercury was nearly fourteen times as heavy as water. The relatively slight variations in the height of the mercury column from time to time indicated corresponding variations in the air pressure, according as it happened to be hot or cold, wet or dry, or whether the observation was taken at the base or at the top of a mountain.

In 1650 another equally interesting observation on air pressure was made by Otto von Guericke, burgomaster of Magdeburg, who demonstrated his discovery before the Emperor Ferdinand III. Taking two copper hemispheres with well-fitting edges, he placed them mouth to mouth and exhausted the contained air as far as he could by means of an air pump. The hemispheres were thus kept in position by the external air pressure, which we know to amount to about 15 lb. on the square inch. It is said that at the demonstration given by Guericke each of the two hemispheres was chained to a team of fifteen horses, but that the combined efforts of the thirty horses failed to separate the hemispheres from each other.

Boyle, with Hooke's assistance, first manufactured a new and improved air-pump, and made numerous experiments with it. In 1660 he published an account of them under the title "New Experiments physico-mechanical touching the Spring of the Air and its Effects, made for the most part with a new Pneumatical Engine." The gist of this book lay in the law of the compressibility of gases, now universally known as "Boyle's Law"—viz. that the volume of a gas at a fixed temperature, multiplied by the pressure, is always a constant. Put in other words, the volume of a gas varies inversely as the pressure to which it is subjected.

Although this important discovery is that by which his name will always be remembered in the history of science, Boyle busied himself with various other subjects, such as the propagation of sound through the air, the expansive force of freezing water, the specific gravities of selected substances, and the curious phenomena of "magnetism," more or less known to the ancients and described by Gilbert some fifty years previously. Gilbert had found that if certain substances, such as amber, sulphur, sealing-wax, etc., were vigorously rubbed with dry flannel, they were able to attract and even lift scraps of paper, feathers, etc. Guericke had struck on the same line of research, and showed that an electrified body attracts a non-electrified one, but repels another electrified body.

Turning now to the claims that have been advanced on Boyle's behalf justifying his title of being the "Father of Chemistry," we cannot say that they are quite convincing. To begin with, he was an alchemist, and believed in the possibility of transmuting the baser metals into gold and silver. But he did good service in criticizing the chemistry of his time, and showing wherein it was unsound. This he did in a book called *The Skeptical Chymist*, where he shows the absurdity of the Aristotelian conception of the four elements, earth, water, air and fire, and the equally worthless alchemical view of the three elements, sulphur, mercury and salt. His notion of a chemical element was a body that was incapable of being decomposed into constituents differing from itself. But he was, of course, unacquainted with modern methods of analysis, and hence substances like lime, potash and magnesia appeared to him as elements. He was quite aware of the difference

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the same treatment His explanation was that the heart contained a vital flame which was distributed through the body, and that this fire was extinguished when air was removed. It seems strange to us that, holding such views, he did not draw the conclusion that air was a supporter of combustion. These rather crude experiments and cruder explanations were, however, the means of stimulating an inquisitive young physician named Mayow to follow the matter up with far-reaching results, as we shall see later on.

We need not spend further time on Boyle's other works, but leave the matter where Pepys left it and yet draw the diarist's conclusion: "I took boat and up the river all alone as high as Putney almost, and then back again, all the way reading and finishing Mr. Boyle's book of Colours,

which is so chemical, that I can understand but little of it, but enough to see that he is a most excellent man." Like a far greater scientist of the centuries to come, Boyle suffered greatly during most of his life from a painful malady, and yet, like Darwin (p. 223), he was able to bear it patiently, saying, "In my laboratory I find that water of Lethe which causes that I forget everything but the joy of making experiments." The true scientific spirit rings out in his remark that he feared death only because after it he would know all things and no longer have the delight of making discoveries.

In order to understand the next stage in the evolution of modern chemistry, it is necessary to refer to a curious theory connected with combustion which was started by two German contemporaries of Boyle, viz. Becher and Stahl, known for over a century as the "Phlogiston Theory." The idea was that a combustible substance consisted of a "calx," or ash, and a mysterious "phlogiston," or inflammable substance, and the proportions in which these two constituents were present varied greatly. Thus charcoal was mainly phlogiston with very little ash or calx, while a metallic oxide was mainly calx with very little phlogiston. When a combustible substance was burned it lost its phlogiston to the air and could regain it only from the air or from some other substance which contained it in excess. Unfortunately the authors of this theory had forgotten the Arabian Geber's discovery that if a metal were calcined in the open it weighed more after the operation than before. To meet this difficulty the phlogistic chemists had to assume that phlogiston possessed "negative gravity," or "levity," since by its loss a body gained in weight. As such a hypothesis was manifestly absurd the theory was ultimately abandoned, but it held its ground until quantitative methods of investigation were introduced into the study of the science.

The next chapter in the story deals with the part played by Mayow, who, as we have just seen, had listened with

keen interest to Boyle's discourses on the effect of placing animals and lighted candles under bell-jars from which the air had been abstracted. Mayow was born in Cornwall in 1645, and after studying medicine at Oxford, practised as a physician in Bath. The only other fact we know of his life history is that he died in London in 1679, when only thirty-four years of age. After meeting Boyle at Oxford he meditated over the phenomena of combustion and respiration, and proceeded, in his own way, to investigate these subjects [illegible] ...he air must con- [illegible] His experiment [illegible] and instructive. He suspended a small piece of camphor along with tinder under a bell-jar, and placed the bell-jar in a water trough, arranging that the water outside and inside the bell-jar should stand at the same level. He then focused solar rays on the tinder, setting the camphor on fire. At first the water level within the jar sank, since the contained gas had expanded owing to the heat, but, when the temperature was again normal, the water rose above the level of that outside. Why? Because there was no "fire-air" or "spiritus nitro-aereus" as he called it, left to continue the combustion of the camphor, the water rising to take the place of what had been used up.

A corresponding experiment with an imprisoned mouse gave the same result, i.e. the water rose within the jar as the mouse went on breathing, and ceased to rise when the mouse died. It was thus clear that respiration was also dependent on "fire-air." From these and other simple but illuminating experiments Mayow concluded that in respiration "fire-air" entered the blood and operated there just as it did when it met the glowing candle. This was really a brilliant discovery, and might have led to far-reaching results had it not been clouded over by the phlogiston theory, which had now come to dominate the minds of chemists. We hear nothing more of Mayow until the rediscovery of "fire-air" (or oxygen) by Priestley, exactly one hundred years later.

Meanwhile a forward step had been taken by a Scottish professor of chemistry named JOSEPH BLACK. Black was the son of an Antrim wine merchant who had settled at Bordeaux, where Joseph was born in 1728. He was educated first at Belfast and afterwards at Glasgow University. Chemistry was at that time a perfectly new subject in university curricula. In 1751 he went to Edinburgh, and in 1754 took his doctorate of medicine there. Two years later he became professor in Glasgow, and later still in Edinburgh.

Black published very little; indeed, we know of only four works that came from his pen, but these were of the highest importance. In 1777 he produced a small treatise entitled *Experiments upon Magnesia alba, Quick Lime and other Alcaline Substances*, the object of which was to determine the difference between what were called "mild" and "caustic" alkalis. Black started with the well-known facts, that a piece of limestone ($CaCO_3$) placed in water undergoes no change, unless an acid be added to the water, when effervescence takes place; and, further, that if limestone be burnt it becomes a powder called quicklime (CaO), which does not effervesce when acid is poured on it, but which swells, gives off heat, and becomes slaked-lime ($Ca(OH)_2$) which again becomes quicklime, by loss of water, when heated to redness. Black set himself the task of discovering the reason for these remarkable phenomena. He first of all found that lime, after being burnt, was lighter than before and that the same was the case after it had been treated with acid. Moreover, he discovered that the weight of the gas given off was exactly equal to the weight lost by the lime during the operation. To this gas he gave the name of "fixed air," seeing that it appeared "fixed" in the limestone before being treated. He next reversed the process by pumping "fixed air" (afterwards known as carbon dioxide) through lime water, when a white precipitate was formed, which he identified as chalk. On experimenting with "fixed air" he found that it put out a flame, and that animals could not live in it. He also discovered that the

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ROBERT BOYLE.

(From the painting after F. Kerseboom in the National Portrait Gallery.)

same gas was given off by certain mineral springs and was developed during brewing operations. These experiments

JOSEPH BLACK, 1728–1799.
(From an engraving after the portrait by Raeburn)

do not strike us as at all remarkable nowadays, but in the end of the eighteenth century they were of fundamental

of them dealt with controversial theological and political matters, and their contents often gave grave umbrage to the orthodox churchmen and state officers. The result was finally a severance of his connection with Lord Lansdowne in 1780, although the marquis very generously continued to provide his pension.

After leaving Bowood, Priestley accepted a clerical post in Birmingham, and at the same time became a member of another "invisible college," which consisted of about a dozen enthusiastic inquirers into Nature's secrets, meeting in each other's houses once a month to discuss matters of scientific interest. Among the dozen were several very famous men, such as Erasmus Darwin, the author of *The Loves of the Plants* and *The Botanic Garden*, and grandfather of the renowned Charles Darwin; James Watt of steam-engine fame; Withering, a distinguished botanist and mineralogist; Thomas Day, the author of *Sandford and Merton*; while visitors to the meetings included Josiah Wedgwood, the well-known pottery manufacturer, Sir Joseph Banks, botanist and traveller and President of the Royal Society, Sir William Herschel, the astronomer, and Smeaton, the architect of the Eddystone Lighthouse. This second "invisible college" was called the "Lunar Society," because its meetings were held on the Mondays nearest full moon, "in order," as Priestley says, "to have the benefit of its light on returning home."

Priestley's continued publication of controversial pamphlets at length rendered him very unpopular in the midland capital, and when he expressed himself in sympathy with the principles of the French Revolution, then at its height, the unpopularity developed into riotous violence. Not only was his house and its contents burnt to the ground, but he and his family only just escaped lynching. The result was that Priestley and his family had to flee to London; but even there he obtained no rest, for the Established Church of the time never missed an opportunity of throwing mud at anything that savoured of dissent, and Priestley received his full share of abuse. Further threats of violence at length

compelled him to leave England altogether and follow the Pilgrim Fathers to the New World, where he lived for the remainder of his life. He died on February 6, 1804.

Priestley's greatest achievement was the discovery, or rather rediscovery, of what came to be called oxygen; but he began by making experiments on Black's "fixed air," and, for the purpose of collecting this and other gases, he employed what is now known as a pneumatic trough. These "kinds of air" were regarded by Priestley as differing from each other according to the amount of the hypothetical "phlogiston" they contained, and it is somewhat remarkable that a man of his breadth of mind should, up to the day of his death, stubbornly adhere to this theory, even though the new views on combustion established by Cavendish and Lavoisier had become almost universally accepted. He found that "fixed air," or carbon dioxide, was very soluble in water and conferred on it a very pleasant and even exhilarating quality, and thus he introduced the principle on which the manufacture of soda water is based.

His method of obtaining "dephlogisticated air," or oxygen, was by placing a quantity of mercuric oxide in the bowl of a retort, guiding the nozzle beneath the mouth of a glass vessel filled with mercury and inverted over a mercury bath. He then applied heat to the bowl of the retort by concentrating the sun's rays on the mercuric oxide by means of a large biconvex lens. The result was the evolution of a gas from the oxide which collected in the inverted receiver, while the mercuric oxide was reduced to metallic mercury. To his surprise the gas collected in the receiver had the power of causing a red-hot taper to burst into flame He observed also that animals kept in such an atmosphere lived longer and were more active than when in ordinary air, and after inhaling the gas himself expressed the opinion that "this pure air may at last become a fashionable luxury. As yet only two mice and myself have had the privilege of br[illegible] ing it." That may be strictly correct, but the germ [illegible] idea lay in the simple experiments carried out [illegible] a century earlier. Further, although Priestl[illegible]

of the fact, this same gas was isolated about the same time by a Swedish apothecary, called SCHEELE. It is true that Scheele's discoveries were not made public until 1777, three years after Priestley's book on *Different Kinds of Air* had been given to the world, but there seems little doubt that Scheele had the real priority. It must be remembered that the usual method of announcing discoveries in those days was not by "reading papers" at learned societies' meetings held at short intervals, but by the publication of books containing the results of, it might be, many years of research, and thus several men might have been engaged on the same problem without any one of them knowing what the others were doing. Hence the scant attention given to Scheele's work until 1892, when all his notes and letters were published in one volume under the ægis of the Swedish Academy of Sciences.

Priestley also made several important observations on the relation of this gas and Black's "fixed air" to vegetation. He put forward the view that the purification of foul air, such as that left after a candle had burnt out in ordinary air under a bell-jar, was effected by green plants which "imbibed the phlogistic matter with which it is overloaded." He describes how a friend of his, while waiting at Harwich for a boat to convey him to the Continent, noticed a horse-trough at the inn where he was staying, which the landlord refused to have cleaned out, because he found that its contents remained longer sweet when the sides and bottom of the trough were "covered by a green substance which is known to be of a vegetable nature." Priestley investigated this phenomenon, and observed the "spontaneous emission of dephlogisticated air from water containing a vegetative green matter," but he adds that he "never found the emission took place save when the water was exposed to light." This observation laid the foundation of a department of plant physiology that is occupying the minds of biological chemists even at the present day. To this question we must return later when we come to consider the development of modern biological ideas.

HENRY CAVENDISH, 1731–1810.
(From a contemporary drawing.)

We must now turn our attention to another contemporary of Priestley, a man of a very different character and reared under conditions as distinct from those under which Priestley worked as can well be imagined. This was the Hon. HENRY CAVENDISH, a scion of the House of Devonshire. He was born in 1731 at Nice, and was educated first

at a private school at Hackney and afterwards at the university of Cambridge, where there is now a permanent memorial to him in the form of the Cavendish Laboratories of Physics. There is no certain evidence of how Cavendish spent the ten years after he left the university in 1753, although, judging from the fact that he published a work on "Factitious Airs" in the *Transactions of the Royal Society* in 1766, it would appear that he had devoted some time to the examination of the various gases that were then the subject of study among chemists.

His name, however, as a scientist of extraordinary ability blazed out on the world when he, in 1784 and 1785, produced his memorable work, "Experiments on Air," published in the *Philosophical Transactions*. It had already been shown that, when common air and another gas called "inflammable air" were exploded within a closed vessel, a deposit of dew formed on the walls of the vessel. Priestley explained this by saying that "common air deposits its moisture by phlogistication"; if he had said by "fogistication" it would have conveyed about as much meaning! Although Cavendish, like other contemporary chemists, was a confirmed adherent of [illegible] heory, he had the conspicuous merit of [illegible] stablished the composition of water, an [illegible] f discovering the nature and properties of hydrogen, or, as he termed it, "inflammable air." He obtained the gas by pouring dilute sulphuric acid over a metal such as zinc in an appropriate vessel and collecting the gas given off in a pneumatic trough. He found that, on mixing a given quantity of this gas with about two and a half times its volume of ordinary air and igniting the mixture, a dew settled on the wall of the container, which he identified as water. For the purpose of his experiment he invented an instrument, called a eudiometer, or measurer of pure air, which consisted of a glass vessel closed at both ends, but provided with screw taps, by which ordinary air could be abstracted by an air pump before being filled with the gases which were under investigation. The modern form of the instrument is a

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JOSEPH PRIESTLEY.

(From the pastel by Mrs. Sharples in the National Portrait Gallery.)

graduated tube hermetically closed at one end, but with two platinum terminals let in so as to enable an electric spark to be passed through the contained gases. Cavendish found that when one volume of "inflammable air" and five volumes of ordinary air were mixed in the eudiometer and then set on fire, all the inflammable air and one-fifth of the ordinary air disappeared, leaving a dew on the inside of the eudiometer, and that what was left over would neither burn nor support combustion, in other words, the inert gas, nitrogen, that had been discovered by Daniel Rutherford in 1772 and named by him "mephitic air." Subsequently Cavendish employed a mixture of "inflammable air" and "dephlogisticated air" in the proportion of two to one, and on combustion obtained pure water. He found, however, that under certain conditions the water resulting was acid to the taste, and that this was the case when the dephlogisticated air was present in excess and that the acid "was always of the nitrous kind."

P [illegible] came to th [illegible] was not [illegible] ality many different substances confounded together by us under the name of phlogisticated air." Experiments to determine this point resulted in his finding that about $\frac{1}{120}$ of the total volume of the atmosphere was something that was neither oxygen nor nitr [illegible] Oxygen=20.833 per cent. a [illegible] the last figure including th [illegible] ciated with the nitrogen. [illegible] closely with those given in modern text-books of chemistry, viz. oxygen=21.00 per cent. and nitrogen=78.06 per cent., the difference in the nitrogen figure being accounted for [illegible]

[illegible]

helium, neon, krypton, and xenon.

proceeded with his real life-work, the overthrow of the phlogiston theory and the establishment of chemistry on a sure foundation.

In one important respect Black had differed from other chemists of his time, viz. in his use of the balance. The value of this instrument Lavoisier was quick to appreciate, for in one of his first experiments he exploded the idea then generally held that water could be turned into earth. He did this by showing that pure water, after prolonged boiling in a glass vessel and on subsequent evaporation, left a residue, but that this did not come from the water but from the vessel in which the operation was carried out, for the deposit corresponded exactly to what the vessel had lost in weight during the boiling. His next exploit was to show that when a metal was changed by burning into its calx, instead of losing something which chemists called phlogiston, it increased in weight, and, further, that when the experiment was carried out in a closed vessel the contained air diminished in weight correspondingly. During the combustion of sulphur and phosphorus in closed and carefully weighed containers he found that these bodies ceased to burn after a certain proportion of ordinary air had been used up, and to the remainder he gave the name of "azote" (Gr. *a*, not; *zoe*, life), since it was incapable of maintaining life. He also burnt charcoal in pure oxygen and obtained Black's "fixed air," which he analysed quantitatively, and found it to be composed of 72 parts of oxygen and 28 of carbon, and consequently renamed it carbonic acid. A fragment of a diamond burnt in pure oxygen likewise produced carbonic acid, thence he concluded rightly that this precious stone was pure carbon.

In 1774 Lavoisier met Priestley in Paris, and the conversations between these two savants led Lavoisier to repeat Priestley's experiments with mercuric oxide, but his explanation of the phenomena he observed was of an entirely different character. In a word, combustion to Lavoisier was a process of oxidation or union of oxygen with other bodies under appropriate conditions. This,

ANTOINE LAURENT LAVOISIER.
(From an engraving after the portrait by David.)

perhaps the most important generalization ever made in chemistry, seems to us a matter so simple and self-evident that we cannot but feel surprised that men like Black and Cavendish did not hit on the solution long before The will-o'-the-wisp phlogiston led men astray, and it took a

man of the calibre of Lavoisier to extinguish, once and for all, the misleading light. It was unfortunate that Lavoisier did not live to blot out another *ignis fatuus* in the shape of "caloric," the "subtle fluid" that was supposed to be the cause of heat.

In 1789 Lavoisier published the first text-book of chemistry—*Traité Eléméntaire de Chimie*—in which the new doctrines were lucidly explained, and which did for that science what Newton's *Principia* had done for astronomy. The text-book revolutionized the nomenclature of chemistry. Combinations of metals and non-metals with oxygen, though not all acids, as Lavoisier thought, now became known as oxides, and the new names oxygen, hydrogen, and azote or nitrogen, replaced the older clumsy and misleading terms. Similarly, when oxygen was found to unite with another element to form a new compound in two different proportions, the lower oxide received the termination *-ous*, and the higher one *-ic*—*e.g.* nitrous oxide and nitric oxide, sulphurous oxide and sulphuric oxide. Further, compounds of these acids with bases to form salts became known as nitrites and nitrates, sulphites and sulphates, and so on. In a word, the nomenclature of chemistry as revised by Lavoisier, owing to the acceptance of his illuminating principles, is that in use at the present day.

Another line of research followed out by Lavoisier was that connected with the estimation of the amounts of heat produced in chemical changes, not only in those taking place in the laboratory apparatus, but also in the much more intricate processes associated with the respiration of animals. From these investigations Lavoisier naturally passed to those concerned with the combustion of organic substances. By careful weighing of such bodies before and after combustion, and by estimating the amounts of carbon dioxide and water produced during combustion, he was able to work backwards and determine the original composition of the substances themselves. In this way he laid the foundations of organic chemistry also.

But the end was near, and it came chiefly through

Lavoisier's unfortunate connection with the Ferme Générale. Accused of plotting against the State, extortion from the public, and adulteration of commercial products, Lavoisier, with twenty-six other *fermiers*, was arrested and con- ... was concerned. ... of his scientific ... s said to have exclaimed, "Savants! The Republic has no use for savants!" Perhaps so, but the world had need of them! Lagrange, the famous French mathematician, was entirely right when he remarked after the guillotine had fallen: "A moment was all that was necessary in which to strike off this head, and probably a hundred years will not be sufficient to produce another like it."

"One hundred and twenty-five years," says Tilden, writing in 1919, "have elapsed since Lavoisier's death, and in the course of this long interval, by successive steps, involving, beside the leadership of genius, the laborious experiments, calculation, and reflection of thousands of men, chemistry has become one of the most complete and scientific branches of human knowledge. That position has been attained only by the consistent adoption of a principle enunciated by Lavoisier in his *Traité Elémentaire*: 'Il n'est jamais permis, en physique et en chimie, de *supposer* ce qu'on peut *determiner* par des expériences directes.' It is this constant appeal to fact that renders the position of systematic chemistry unassailable."

CHAPTER VII

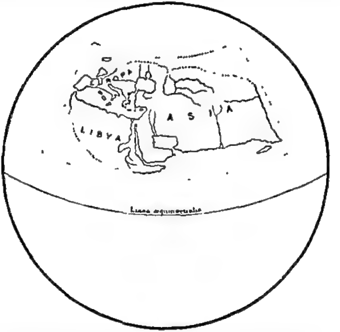
THE STORY OF THE EARTH

IT was only to be expected that the philosophers of Greece and Rome, who, as we have already seen, speculated so acutely on the nature and origin of the universe beyond the bounds of the insignificant morsel of it on which they lived, should also have made attempts at interpreting the natural phenomena presented to them by the earth itself. Nor was it unnatural that these interpretations should have been associated with the doings of the gods and demigods that figured so prominently in the legends and myths that stood for much of what represented history in those days.

By the time of the geographer Strabo (54 B.C. to A.D. 25) people had begun to hold saner views as to the origin of natural phenomena, and legends connecting them with the deities of Olympus, or their numerous heroic and semi-human progeny, were either quite ignored or dismissed with contempt. The general conclusions they arrived at did not differ so very much from those we hold to-day, and fully support the views attributed to the ancient sage, Pythagoras, as given by the Roman poet Ovid, a contemporary of Strabo, in the following words: "Nothing in this world perishes, but only varies its form; to be born is merely to begin to be something different from what we were before, and to die is to cease to be that same thing. In spite of all transformations, the sum of everything remains constant." Heraclitus said the same thing in two words: πάντα ῥεῖ—everything flows.

What was once dry land is now sea, and what was sea

has become land, for marine shells are to be found high up the mountain sides. Plains have been carved into valleys by rivers, and, little by little, hills are washed into the ocean. Inland waters have become deserts and arid wastes have been changed into swamps New springs have arisen in



THE WORLD-ISLAND ACCORDING TO STRABO, A.D 18.

(The blank space within the circle is one vast sea surrounding the world)

some places and have dried up in others, some of them inflammable (petroleum) and some others capable of petrifying organic bodies Earthquakes have opened up fissures and engulfed rivers What are now islands were once joined to mainlands, and parts of continents have been separated off as islands The land has often risen and as often sunk, for cities can still be seen lying beneath

the level of the waters. Mountains have been tossed up into the air by subterranean convulsions, or have vanished by the collapse of enormous underground caverns. Volcanoes are safety-valves for gases and fires imprisoned beneath the earth's crust, and a day will come when volcanoes will cease to burn, when the subterranean fuel becomes exhausted. These were some of the views held in the Augustan age, and it will be noted that they are based on a belief, though perhaps not definitely expressed, that the world was governed by law and not by capricious deities operating entirely by impulse. Further, these interpretations of the phenomena of nature were promulgated without opposition from a pagan theology that had lost its hold on people's minds, or from public anger arising from superstitious beliefs that were no longer regarded as anything more than children's fairy tales.

Just as was the case with the other sciences, such knowledge of geological phenomena as survived the fall of the Roman Empire was kept alive by the Arabs, as, for instance, in the writings of Avicenna (A.D. 980–1037), who translated Aristotle's works and paraphrased them to suit his own ideas; but, later on, these broad and, on the whole, san views of cosmogony were observed not to be in accordan with the account of the creation given in the book Genesis, and therefore were taboo. "To teach that t world must be many thousands of years old was plainly contradict the received interpretation of Scripture that more than six thousand years had elapsed since the tim the creation." Having no desire to earn a cheap ma dom, men were driven to invent all sorts of weird exp tions of such observed facts as the occurrence of shells and fishes embedded in the rocks, and which therefore, spoken of as mineral concretions, spo nature, imitations of organisms due to some mys "plastic force," or even to the influence of the stars! even went the length of suggesting that fossils were in the rocks by the Creator (some said by the de mislead and perplex mankind. The usual explanat

that most commonly accepted, was that fossils were the remnants of animals that had perished in the Noachian Deluge. A Swiss naturalist named Scheuchzer, as late as 1709, published a great work on the supposed remains of the Flood, and described a giant salamander under the name of *Homo diluvii testis*, which he believed to be the skeleton of a man who had been an eye-witness of that traditional catastrophe! And yet, more than two hundred years before Scheuchzer's day, the great Italian artist and engineer, Leonardo da Vinci, held that shells that he had discovered while superintending the construction of a canal in northern Italy, were the remains of marine mollusca once living on the seashore and subsequently buried under silt brought down by rivers, and supported his conclusions by pointing to the water-worn pebbles and gravels in the terraces high up the mountain sides.

One of the most distinguished of the geologists of the seventeenth century was the Dane, NICOLAS STENO. He was born in 1631 at Copenhagen, where he studied medicine. After visiting Holland, France and Austro-Hungary, he finally settled in Florence, where he became physician to the Grand Duke. After various vicissitudes he ultimately changed from the Protestant to the Roman Catholic Church, in which he took orders and rose to be Vicar Apostolic in the north of Europe, devoting himself entirely to the compilation of religious works. He died in 1687.

Before Steno's conversion to Catholicism he published, in 1669, his famous treatise, *De Solido intra solidum naturaliter contento*, a work that stamps him as a man possessed of keen observational powers and sound reasoning ability, tempered, however, by a certain timidity of expression, doubtless engendered by the fear of awakening the antagonism of the ultra-orthodox. As Steno's book is the first real contribution to geological science, it is worthy of something more than a mere passing reference. No one has summarized more succinctly Steno's achievements than our old teacher, Sir Archibald Geikie, whose words will

arry more weight than any digest we can make. "He as the first clearly to perceive that the strata of the earth's crust contain the records of a chronological sequence of events, and that the history of the earth must be deciphered from them. He laid down for the first time some of the fundamental principles of stratigraphy. He recognized the predominant influence of running water in carving out the inequalities on the surface of the land. It is true that he had no clearer notions than had obtained for so many centuries regarding the true nature of volcanic action, which he still regarded as due to the subterranean combustion of carbonaceous substances. He was hampered, too, by the prevailing theological doctrine that the earth could not be more than some six thousand years old, and that the fossiliferous strata had been mainly deposited during or since Noah's Deluge. But his name must be enrolled high in the list of those who, by careful observation and deduction, helped to lay the foundations of modern geology."

"The progress of geological inquiry in Europe during the seventeenth century," continues Geikie, "was masked by a characteristic feature—the development of a series of cosmogonical systems, in which the only common basis of speculation was the effort to account for the origin of our globe and of our universe, in harmony with the teaching of the Church. Science had not advanced far enough to afford any firm basis for speculations of this nature, and consequently the lack of data was in too many cases sup plied by wholly imaginary pictures of the history of creation The systems of cosmogony thus framed, though some o them attained considerable fame in their day, obstructe the progress of inquiry, inasmuch as they diverted attenti from the observation of nature into barren controve about speculations. . . . It was a long time before m came to understand that any true theory of the e must rest upon evidence furnished by the globe itself, that no such theory could properly be framed until a body of evidence had been gathered together."

This being the case, we may pass over the v

treatises that appeared in the succeeding decades by men like Burnet, Whiston, Woodward, Hooke, Ray and others, and turn to those who, towards the end of the seventeenth century and the early years of the eighteenth, actually did make some progress towards elucidating the history of the earth. The really philosophical method was to start at the very beginning and endeavour to arrive at some conception of how the world originally came into existence.

the earth to have been originally a glowing mass thrown

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detail.

The distinguished French naturalist BUFFON (1707–88) had also something to say about the first beginnings of the earth in the introduction to his *Natural History*, published in 1749. In a curious book called *Époques de la Nature*, which appeared nearly thirty years later, he divided the history of creation into six (or seven) epochs corresponding to the " days " of the book of Genesis, which he held had no relation to days as we understand the term, but his distribution of the labour of creation was very different from that of the Hebrew writers.

In the first epoch the earth was a molten mass just cast off from the sun, gradually cooling as it rotated, but maintaining an incandescent core within a solid crust, which was covered by a hot enveloping atmosphere. The second epoch was occupied by the solidification of the globe and the formation of mountains and valleys, but there was still no water, and the crust was far too hot to permit of any life upon it. Then came the third period, during which the crust became cool enough for water to

COMTE DE BUFFON, 1707–88.
(*From an engraving after the portrait by Drouais.*)

condense, and this condensation progressed until th
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This was to permit of marine shells being deposited o

what were, in the future, to be mountains. Then the waters cooled and subsided sufficiently to allow of islands appearing, covered with vegetation. In the fourth epoch the superfluous water sank through fissures in the crust, permitting the sea to reach its present level, while the forests were engulfed along with the water, providing fuel for keeping volcanoes going. This was a tempestuous time on the earth, and no terrestrial life could exist until the conditions became more peaceful, as they did in the fifth epoch. This was the age of the giant mammals that flourished in the genial climate of the Northern Hemisphere. The sixth epoch saw the separation of the Old and the New Worlds and the formation of the great islands, and all this took place some 10,000 years before the birth of man, to whose evolution Buffon devotes the seventh epoch.

This vision of creation was of course entirely contrary to the Mosaic account, and Buffon was hard put to it to conciliate his clerical friends—and enemies—in the Sorbonne, before actually releasing his book to the general public. Fantastic as Buffon's dream seems to us nowadays, it had two outstanding merits. In the first place, it recognized that the earth had itself a long history, and one which, given patient research, could be followed from the earliest times to the present day, even although chapters, not to say volumes, of it were missing; and, secondly, that the paltry six thousand years that the ecclesiastical authorities allotted to the age of the earth was far too short a time to allow for the tremendous changes that had occurred upon it since first

> "The heavens and earth
> Rose out of Chaos"

While Buffon was picturing to himself the broad outlines of the history of the globe, a fellow-countryman of a very different temperament was examining the minute structure of the minerals of which its crust is composed. This was JEAN ÉTIENNE GUETTARD (1715–86), a man of prodigious energy and a most voluminous writer, but one

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who was scarcely at all recognized as one of the founders of geology until the present century. His name is chiefly associated with the construction of the first geological maps and with the discovery of the volcanic origin of the hills of Auvergne. More than any one of his predecessors he appreciated the value of fossils as landmarks in geological history, and published many memoirs upon them. "By his minute and laborious researches he did more to advance the true theory of the earth (on which, however, he never allowed himself to hazard a single conjecture) than the philosophers who have racked their brains to devise those brilliant hypotheses, the phantoms of a moment, which the light of truth soon remands into eternal oblivion" (Condorcet).

The tale of distinguished French geologists is by no means yet complete; at least two great names remain to be added to the roll, viz. those of Desmarest and De Saussure.

NICHOLAS DESMAREST was born in 1725, the son of humble parents, so poor that they could not afford to give him even a school education, and, had it not been for the interest taken in the boy by the parish priest, the chances are that he would never have reached the eminence he subsequently attained. When a lad of fifteen he was taken in hand by the Oratorians of Troyes, and by them sent to Paris, where, while studying mathematics and physics and finally geology, he supported himself by private tuition. While still a young man he wrote an essay on the possible past land connection between England and France, in competition for a prize offered by the Duc de Chaulnes. This essay attracted the attention of the famous D'Alembert, the encyclopædist, who introduced him in turn to the Duc de la Rochefoucault. Through this noble's influence Desmarest was appointed Inspector of Manufactures, a post he held until the Revolution cut short the life of his distinguished patron. He himself, more fortunate than Lavoisier, narrowly escaped a similar fate. After the madness of the Reign of Terror had passed, Desmarest

resumed his position, and had much to do in the reorganization of French industries during the Empire.

Such time as he could spare from practical and official duties of this kind he devoted to wanderings over the country, always on foot, with a meal of bread and cheese in his knapsack, sleeping on the hillsides or in shepherds' huts, and gleaning information of all kinds from the various workmen and artisans he encountered on his travels. One of his excursions took him into the region of Auvergne, rendered classic by the labours of Guettard a dozen years before.

The feature that chiefly attracted his attention was the mysterious pillars of columnar basalt, so well developed not only in that region, but also in various other parts of Europe, and so familiar to tourists in our own country in the Giant's Causeway and the Western Isles. The puzzle of the origin of these formations lay in the fact that they were to be found in regions which showed no signs of volcanic action, but appeared on or even between undoubted sedimentary rocks, and were generally believed to have been, like them, laid down in the sea. A careful study of these formations in Auvergne led Desmarest to express the view "*that prismatic basalt belonged to the class of volcanic* products, and that its constant and regular form was the result of its ancient state of fusion . . . Further, I am fully persuaded," he adds, "that in general these groups of polygonal columns are an infallible proof of an old volcano, wherever the stone composing them has a compact texture, spangled with brilliant points, and a black or grey tint." After several years spent in investigating similar formations in Central Europe, he at length published his memoir on the subject in 1774.

One of his conclusions was of especial interest. He had noticed how the basalt often lay in patches, or outliers and convinced himself that these outliers "capping the ridges and plateaux are really remnants of once continuous sheets of lava, and that their isolation, together with the removal of their original covering of scoriæ and slags, is to

be ascribed to the operations of rain and melted snow. The depth of the valleys cut through these lava-platforms was found by him to be commensurate with the antiquity of the lavas, and with the size of the streams that flowed between the severed escarpments" (Geikie). Thus Desmarest laid the foundation of the doctrine of denudation, emphasized so strongly in every modern text-book of geology. "Nature," he said, "followed the same order of procedure in the most remote ages as in the most recent times."

In so far as his personality is concerned, there is much to remind us of his famous English contemporary, Cavendish. Like that physicist, he was extremely methodical in his habits, always rising, feeding and retiring to rest at the same hours; passing every Sunday in a visit to a friend at Auteuil, and making the same pilgrimage on foot, even after his friend had passed away, continuing the practice at the age of eighty-five, when his family compelled him at last to employ a carriage. Like Cavendish, also, he never changed the cut of his clothes, and still wore the dress and wig i
vogue two generations before his day. "The Academ
of Sciences," wrote Cuvier, "saw in him, as it were, th
ment of a bygone age, one of those old philosophe
too few, who, occupied only with science, did not wa
nselves in the ambitions of the world, nor in rambl
ough too wide a range of study, men more envied th
tated, who have supplied us with that successio
togenarians and nonagenarians, of which our histo
ll. Living like these worthies, Desmarest fulfilled a si
areer, and reached, without infirmities or any grave ma
he age of ninety years. He died on the 20th Sept
1815. During his protracted lifetime he saw the Ac
twice renewed. Among so large a number of colleag
doubtless recognized that there were many who e
or even surpassed him in enlightenment or in menta
but he had the happiness to be assured that h
would last as long as that of any one among them."

In the year 1740 there was born in Geneva, the

his even more famous son, Theodore, whom we shall meet with later on as one of the founders of vegetable physiology. The father must have been precocious when a youth, seeing that he became a professor at the age of twenty-two. Beginning as a botanist, he branched off into physics and geology (a name he was the first to use), but returned to his first love in his later years. To him belongs the credit of being

débris of the mountains in moraines on the plains below. Unfortunately for science he died of paralysis in 1799, when only fifty-nine years of age

It has often been pointed out how slowly the conception of a geological succession of the rocks forming the earth's crust arose in the minds of those who made geology their life study. What we term stratigraphical geology was not really born until the beginning of the nineteenth century, when the Scottish school of geologists began to replace the French school, as leaders in working out the history of the earth and the successive changes it had undergone.

Before the rise of that school, however, many names crop up as exponents of certain principles, or as contributors, in greater or lesser degree, to the accumulation of data that were to be built up into the architecture of the science as we now know it.

One of these names that for long held a prominent place in the history of geology was that of ABRAHAM GOTTLOB WERNER (1749–1817) Geikie sums him up in the following words "I am compelled to arrive at the conclusion that, although he did great service by the precision of his lithological characters and by his insistence on the doctrine of geological succession, yet that as regards geological theory, whether directly by his own teaching, or indirectly by the labours of his pupils and followers,

much of his influence was disastrous to the higher interests of geology." That he was a teacher *par excellence* cannot be denied. As Geikie admits, " no teacher of geological science either before or since has approached Werner in the extent of his personal influence or in the breadth of his contemporary fame"—with the exception, we would claim, of Geikie himself.

Into the evanescent and useless controversy between the Wernerians or neptunists, who held that all rocks were laid down in water, *i.e.* were of aqueous origin, and the vulcanists, who believed that many rocks, such as basalt, had an igneous origin, we need not enter. The hatchet has long since been buried, for there is now no neptunist left to attack. " It was not his writings, nor even his opinions and theories in themselves, that gave him his unquestioned authority among the geologists of his time. His influence and fame sprang mainly from the personality of the man. . . . His followers, indeed, captivated by the precision of his system and its apparent applicability in any and every country, claimed for him the highest place in the ranks of those who had studied the history of the earth. But the exaggeration of their claim was amply shown by the rapidity with which the Wernerian doctrines began to fall into disrepute even before the death of their author." (Geikie.)

The scene now shifts from the volcanoes of Auvergne and the snow-clad peaks of the Alps, that had witnessed the triumphs of Desmarest and De Saussure, and the plains of Saxony where Werner preached, to the

> " Land of brown heath and shaggy wood,
> Land of the mountain and the flood,"

where JAMES HUTTON laid securely the foundations of the modern conception of the theory of the earth. He was born in Edinburgh on June 3, 1726, within an easy walk of a museum in miniature, that has formed the demonstration ground for many generations of geological students, Arthur's Seat and Salisbury Crags. His father was the

JAMES HUTTON, 1726–97.
(From the portrait by Raeburn.)

city treasurer, and, at his death, left young Hutton a small property in Berwickshire, so that the future geologist had not to earn his bread like so many others before him who have advanced the cause of science

After leaving the High School and after a brief appren-

ticeship to law, he entered the university with the view of becoming a medical practitioner. He completed his studies in France and took his degree at Leyden in the Low Countries. His early taste for chemistry seems to have influenced him in taking up scientific farming, and, to qualify himself for this line of life, he gave up medicine and settled in Norfolk, in order to master the practical side of the question. It was here that his thoughts first turned to geology, and the knowledge he acquired both of the culture of crops on the surface of the soil and of the nature of the rocks from which that soil was derived, stood him in good stead when, in 1754, he returned to cultivate his own little estate in Berwickshire.

Although he remained ostensibly a gentleman-farmer for the next fourteen years, he was really studying deeply the great questions in geology that had been occupying the attention of the French geologists during the whole of the eighteenth century. In 1768 he let his farm and came to reside in Edinburgh, where the facilities were greater for scientific research, and where he was able to cultivate the acquaintance of men like Black, the discoverer of "fixed air," who was always ready to aid him with his counsel and advice.

Hutton read widely and digested what he read, giving the results of his labours to the world in the form of memoirs on a variety of subjects; but his chief interest lay in geology, and for more than a quarter of a century he patiently collected all the information he could obtain, not merely from books, but also from a first-hand study of the instructive material lying to his hand in and around Edinburgh and farther afield in the British Isles.

Along with Black he took a keen interest in the foundation of the Royal Society of Edinburgh, which obtained its charter in 1783, and it was at an early meeting of this body that he read the first draft of his great work, *A Theory of the Earth, with proofs and illustrations*, which was published in 1795.

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vigour of his mind. His high forehead, firmly moulded features, keen observant eyes, and well-shaped, rather aquiline nose, marked him out at once as a man of strong intellect, while the gentleness that beamed in his face was a reflex of the kindliness of his nature. His plain dress, all of one colour, gave a further indication of the unostentatious simplicity of his character." (Geikie.)

In 1793 he suffered from a severe illness, but recovered, until a second attack prostrated him in the end of 1796 [illegible] of 1797.

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The central idea of Hutton's thesis is that what is happening now on the earth is of precisely the same nature as what has happened in the past His wanderings over the country had taught him that beneath the surface soil there lay beds of sandstone, limestone, shale, gravel and so on, all of which were manifestly derived from older rocks, but all resembling layers of detritus now in process of formation under the sea, and he argued that if such depositions were taking place now, so they must have taken place in the past; the rocks of one age were the compressed sediments formed by the erosion of land surfaces of a previous age He was thus led to recognize primary rocks, and, over them and formed from them in turn, secondary strata, all solidified by subterranean heat, modified by pressure. Further, these strata, once horizontal, as they must have been if slowly deposited in the sea, were now bent, twisted, folded and tilted up on end, and hence must have been subjected to tremendous convulsions of nature in the dim

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past, convulsions that he traced back to gigantic internal forces originating in the molten interior of the globe. Into the nature of these forces he did not enter, holding "that it is no part of the province of geology to discuss the origin of things."

The next problem was to account for unstratified rocks, which he did by suggesting that these had been originally molten and injected from below into primary and secondary stratified rock during some of the ancient upheavals that had tilted, bent and fractured them, and often causing secondary changes in the deposits into which they had been forced while in a molten state. Granite was thus an igneous rock, and not an aqueous one as taught by Werner.

Another principle emphasized by Hutton was the universality of aerial waste. Mountains were constantly being eroded by rivers and being carried down piecemeal into the sea; subaerial denudation was a potent factor in determining the topography of the land. Hutton also laid stress on the great transporting power of glaciers, and Playfair, paraphrasing Hutton's terse sentences, describes how "before the valleys were cut out in the form they now are, and when the mountains were still more elevated, huge fragments of rock may have been carried to a great distance; and it is not wonderful if these same masses, greatly diminished in size, and reduced to gravel or sand, have reached the shores or even the bottom of the ocean." Here, as Geikie points out, was foreshadowed the former much greater extension of glaciers in geological history, as described more fully in later years by Agassiz and by James Geikie, brother and successor of the author from whose works we are quoting so freely. The whole conception of the evolution of the earth as it exhibited itself to Hutton is summed up in Longfellow's often quoted verse:

"And Nature, the old nurse, took
The child upon her knee,
Saying, 'Here is a story-book
Thy Father has written for thee.'"

Hutton truly followed Bacon's advice—"about Nature, consult Nature herself." He started with no preconceived ideas and accepted no principle that was not substantiated by actual facts, recognizing that "you can't alter facts by *filming them over with dead romances.*" *The concluding* sentences of his book express his views more clearly and succinctly than any paraphrase.

"In interpreting Nature," he says, "no powers are to be employed that are not natural to the globe, no action to be admitted of except those of which we know the principle, and no extraordinary events to be alleged in order to explain a common appearance. The powers of Nature are not to be employed in order to destroy the very object of those powers; we are not to make Nature act in violation to that order which we actually observe, and in subversion of that end which is to be perceived in the system of created things. In whatever manner, therefore, we are to employ the great agents, fire and water, for producing those things which appear, it ought to be in such a way as is consistent with the propagation of plants and the life of animals upon the surface of the earth. Chaos and confusion are not to be introduced into the order of Nature, because certain things appear to our practical views as being in some disorder Nor are we to proceed in feigning causes when these seem insufficient which occur in our experience"

Once the fundamental truth of Hutton's theory is recognized, there remains little more to be said in regard to the further development of geology into the stately and well-ordered science we see to-day The geological succession of strata, the serial volumes, of which so many are missing, told the story of the past to those who could read what remained, and fill up correctly the gaps that were left by the employment of a restrained and critical imagination, who could interpret the fossil remnants preserved in these strata in such a way as to fix chronologically the periods they respectively represented, just as the palæographist might determine the date of a manuscript

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ne form of its lettering or the style of its illumination. ng these historians of the past are men like Lamarck, er and Brongniart, among palæontologists; but the ırs of these great men, though essential to the correct pretation of the succession of strata, may perhaps be appropriately considered in connection with the growth e youngest of the sciences, viz. biology. On the other , the stratigraphical sequence of the rocks was studied in detail from a more strictly geological aspect by like William Smith, Sedgwick and Murchison. Finally, combined results of the investigations of these and y others found their expression in the classic text-books yell, Ramsay and Geikie, so familiar to every student ology at the present day.

from among those who have added so much to our vledge of the structure of the earth and who lived ng the nineteenth century one may be selected, to whom ngs the credit of being among the first to work out sequence of strata, at least in Great Britain. This is LIAM SMITH, the son of a mechanic of Oxfordshire. was born in 1769, and, after a preliminary education, ted, as usual, by lack of funds, he became assistant surveyor. His occupation necessitated his travelling the length and breadth of the land, and thus he abundant opportunities for observing illustrations what he was already convinced of, viz. that there a regular succession in the strata of the country, further, that "each stratum contained organized ls peculiar to itself, and might, in cases otherwise otful, be recognized and discriminated from others it, but in a different part of the series, by examina- of them."

The results of his investigations, spread over many s, were at length placed on record in the form of a ogical map, one of the first ever made, published in . This map was the forerunner of the great series harts which began to be prepared by the Geological vey more than a generation later.

As in his youth, so also in middle age, he found himself in serious financial difficulties.

> "Haud facile emergunt, quorum virtutibus obstat
> Res angusta domi"

House, furniture, books—all had to be sold to meet the claims made on him when a company in which he was interested became bankrupt; all that he retained were his "maps, sections, drawings and piles of manuscript, which were so precious in his own eyes, but for which nobody would have been likely to give him anything." By 1828, however, the outlook improved, and he became land-steward to an estate in Yorkshire, while the Government conferred on him a Civil List pension. The closing years of his life (which ended in 1839) were thus spent in rather more comfortable circumstances.

Beyond his maps he published little. "His range of geological vision was as limited as his general acquirements He had reached early in life the conclusions on which his fame rests, and he never advanced beyond them. His whole life was dedicated to the task of extending his stratigraphical principles to every part of England. But this extension, though of the utmost importance to the country in which he laboured, was only of secondary value in the progress of science." (Geikie.)

Of the achievements of more recent labourers in the field of geology it is unnecessary to speak, for these are incorporated in every modern text-book. "Geology now possesses a large and ever-growing body of well-ascertained fact, which will be destroyed by no discovery of the future, though it will doubtless be vastly augmented, while new light may be cast on many parts of it now supposed to be thoroughly known."

CHAPTER VIII

THE NEW HEAVENS AND THE NEW EARTH

WHEN Newton died in 1727, and after people l to appreciate the magnitude of his work, thought that there was little or nothing left to disc although Newton himself had said that the immense of truth still lay unexplored before him. Although l century had to elapse before the next great name in nomy appeared on the horizon, the intervening years by no means barren, and one of the discoveries made d this period had far-reaching results.

In the days of Galileo light appeared to travel in taneously, though that sagacious old philosopher h suspicion that, just as sound took five seconds to tra mile, so light might also take a measurable time to from a luminous body to the eye. We now know Galileo's suspicion was justified, and the first to dis a basis for it was a Dane, called RŒMER, who reache conclusion after observations made on the revolutio Jupiter's satellites. The times of the eclipses of these b when passing into Jupiter's shadow could, of cours calculated, but it was found that they did not always place at the predicted moment. It then occurre Rœmer that, since the diameter of the earth's orbit 190 millions of miles, the light reflected from Jup moons would have that much farther to travel wher earth was at its farthest distance from Jupiter. The crepancy between the actual and the predicted mo of the eclipse was 16 min. 36 sec., or approximately sec., hence that time was taken by the beam of lig

crossing the earth's orbit. The velocity of light was, therefore, 190,000 miles per second, a very close approximation to the modern estimate of 186,000 miles. A more recent estimate of the speed of light is given by Michelson (1926) as 187,372 miles per second.

When one drives along a road, two distant objects, to right or left, *appear* to alter their relative positions, but the farther off they are the less apparent is the shift. Any two stars must show a similar shift as we move from one side of the earth's orbit to the other, unless the stars are all at the same distance from the earth.

At this point it may be convenient to anticipate discoveries made only within quite recent years, by attempting to gain some conception of the prodigious distances these *flammantia moenia mundi*, as Lucretius called them, lie from our earth. To take an illustration, the great star "Betelgeuse" in the constellation of Orion, whose diameter is estimated to be almost that of the orbit of Mars, or 215,000,000 miles, is so far distant from our earth that a special nomenclature has to be invented to express the figure. The term used by astronomers is a "light-year," *i.e.* the distance light travels in one year at the rate of 186,000 miles per second. Seeing that there are 31,536,000 seconds in a year the number of miles in a "light year" is 5,865,696,000,000, and yet "Betelgeuse" is estimated to be 160 "light years" distant from our earth! Astronomers tell us, nevertheless, that "Betelgeuse" is, comparatively speaking, a near neighbour of ours, as contrasted with some of the star clusters that have been seen and photographed. "Only four stars are known to be less than ten light years distant, so that when a new star suddenly blazes out in the Milky Way, and passes rapidly through its changes of light, we are watching events that transpired hundreds of years ago" (Hale). Truly the boundaries of the stellar universe have been pushed into space far beyond the paltry limits imagined by the Roman poet!

These and other great advances in our knowledge of the "New Heavens" were not made in one stride, but were

achieved gradually, and we must now glance at some of the steps by which they were reached.

In 1693, six years after Newton's *Principia* was published, there was born at Sherborne in Gloucestershire, one who was destined to become a worthy successor to Rœmer. This was JAMES BRADLEY, a member of an old-established family in county Durham. When an undergraduate at Oxford he was much in the company of his uncle, the Rev. Dr. Pound, himself an astronomer of repute. While still in his teens Bradley, in conjunction with his uncle, made an attempt at estimating the distance of the sun from the earth, and came very near the mark.

In 1721 Bradley became Savilian professor of astronomy at his old university. With instruments at which we would look askance nowadays, Bradley observed the transit of Mercury over the sun's disc, measured the size of Venus and followed the course of Halley's comet. It was at this time, about 1723, that he set about endeavouring to measure the distances of the stars, employing the apparent shift in their relative positions as seen from opposite sides of the earth's orbit. For this purpose he selected a star in the zenith, known as Beta Draconis, to avoid the atmospheric refraction which would otherwise have vitiated his observations. He started work in December, hoping to get a maximum result in the following June, when the star was calculated to have shifted to the north. After a few days Bradley, to his great surprise, found that the star was shifting towards the south, and this southward trend continued until March, when it began to move north again, and finally, in June, was in the position it occupied in the previous December. Thereafter it shifted northwards until, in September, it once more turned south, and in December reached its old situation of the year before. As other stars behaved in the same way, Bradley was shunted off his original problem to the consideration of these novel movements. At length he arrived at the doctrine known

JAMES BRADLEY, 1693–1762
(From the portrait by Thomas Hudson in the National Portrait Gallery)

as the "aberration of light," *i.e.* the apparent movement of every "fixed star" in a small circle in the heavens, due to the combined effect of the earth's annual movement and the time that light took to travel to it from the observed star.

Another discovery quickly followed. Bradley found

MARQUIS DE LA PLACE.
(From an engraving after the portrait by Nagron)

presently associated with himself another famous mathematician, LAGRANGE, and these two youthful savants, armed with mathematical methods which were only in their infancy in Newton's day, set themselves the task of unravelling the *arcana celestia*, and the results were at

that when the aberration was complete, still the star did not return to the precise spot it had apparently occupied in the previous year. It had long been known that the plane of the earth's axis was inclined, and, further, that the north pole, which at present points approximately to the pole star, is describing a small circle in space, a revolution which is completed in about 26,000 years. Bradley's new discovery was that this circle was not uniform but sinuous, sometimes on one side, sometimes on the other side of the true circle. To this nodding or oscillatory movement, which was accomplished in nineteen years, the name "nutation" was given, and the cause was found to be the attraction of the moon on the swollen equatorial region of the earth. These two discoveries marked Bradley out as an astronomer of the first rank, and were recognized by his appointment as Astronomer Royal in 1742. During the last years of his life he suffered from melancholia, and died in 1762 at the age of seventy.

In days gone by there were many philosophers who speculated on the origin of the earth, the solar system and even of the universe. These were problems that demanded solution, the *arcana celestia*, as Tacitus called them, must be penetrated. From Thales, 600 B.C., down to Buffon in the eighteenth century A.D., theories galore had been put forward, but one by one they had their day and perished, and men were still awaiting some rational hypothesis to account for the origin and evolution of the universe. It was given to one man to formulate a more abiding theory, Pierre Simon, the son of a French farmer, but eventually Marquis de LA PLACE.

Laplace was born in 1749 at Honfleur on the Seine, and when a mere youth obtained a written introduction to D'Alembert, then one of the most distinguished of French mathematicians. The letter produced no effect, but an essay on a dynamical problem did, and D'Alembert was so struck with the young man's ability that he obtained for him a professorship in the École Militaire at Paris. Laplace

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(From an engraving after the portrait by Naigeon.)

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length given to the world, 1799, in the *Mécanique céleste*, "one of the most difficult books to understand that has ever been written." How much of this classic is due to Laplace and how much to Lagrange has been, and still is, a matter of dispute; Laplace, indeed, has been accused of almost ignoring his colleague altogether. Be that as it may, the two men remained close friends till the end.

In another volume, entitled *Système du Monde*, Laplace gave a more popular account of the theory with which his name will ever be associated—the "Nebular Hypothesis." In this work he draws attention to the fact that not only do all the planets revolve round the sun in the same direction, but that their rotations on their respective axes are directed in a similar manner, as are also the motions of their satellites. How was this uniformity in motion to be explained? The nebular hypothesis was Laplace's answer.

He supposed that, in the beginning, the sun, the planets and their satellites were "without form and void," a vast mass or nebula, probably gaseous. This nebula was rotating at a tremendous speed, and was at a prodigiously high temperature, when even the hardest metals were in the condition of incandescent vapour. Laplace assumed that his gigantic cloud, as it began to cool, began also to condense, most of it into an immense central mass, surrounde by an envelope of as yet uncondensed materials. In thi envelope secondary condensations took place, so that a length the condition was reached of a central rotating co round which revolved, in the direction of the origi rotation of the core, secondary smaller masses, also rotat in the same direction on their own axes, while some of th gave off yet smaller condensations, obeying the same of motion, but subservient to their own particular pa planets. These gaseous condensations would, in the co of ages, lose their heat and become first liquid and then and form the planets and satellites of the solar system; the great central mass, being so immensely larger, retain its semi-gaseous state and its primeval hea

become in the long run our sun. In the case of Saturn, one subsidiary whorl has not yet broken up into satellites, while the ring of asteroids that lies between Mars and Jupiter is now regarded as, probably, a nebular ring that has condensed into over a thousand nuclei, instead of one or a few.

At the beginning of this chapter it was hinted that fifty years would have to elapse after Newton's death before the next great astronomer made his appearance; this

L. He was the son of a
Hanover, at that time
was also trained as a

musician, and was for a time an instrumentalist in the Hanoverian Guards. After a couple of years' service he deserted the army and settled in England, ultimately residing in Bath, where he performed before the noble and distinguished habitués of that fashionable spa. His life there was a particularly arduous one, for although his bent was entirely towards mathematics and astronomy, the necessity for earning a livelihood compelled him to devote as much as fourteen hours a day to teaching his numerous musical pupils, conducting concerts and composing.

In 1772 Herschel went over to Hanover and brought back with him his favourite sister, Caroline, to whose devotion to his interests he owed so much in after life She not only kept house for him but acted as his amanuensis and assistant in all his astronomical labours It must have been a particularly strenuous life for a girl of twenty-two, and her diary gives a vivid picture of the home life in Bath, with its daily round of household work, musical training, and star-gazing often far into the night

Herschel's great ambition was to possess a telescope of his own At first he hired or borrowed one, but finding it unsatisfactory he determined to construct one himself, and this he at length accomplished with the assistance of his brother Alexander, who had joined him in England Caroline gives a pitiful account of the condition of their

house at this period, a condition which must have been particularly distressing to one brought up in all the traditions of the German *Hausfrau*.

We must pass over his early struggles and disappointments and turn to Herschel's great work, which was nothing less than to turn his telescope systematically to every part of the heavens, recording everything he saw, whether previously known or not, a process called "sweeping." On March 13, 1781, he made his first great discovery. While examining a part of the constellation called "Gemini," he observed a star that seemed different from the others round it. A star as seen through the telescope appears merely as a point of light, but this one showed itself as a disc. It was estimated to be about one hundred times as large as the earth and twice as far away as Saturn. In short, Herschel had discovered a new planet, a new member of the solar system, a new companion to the five planets which had been known from the earliest times to the days of Newton. The stranger was christened "Uranus."

This great discovery at once brought Herschel into universal notice and altered the whole current of his life. Honours were poured on him, and he was summoned to Windsor to demonstrate his discovery before the king, whose service he had deserted so many years before. His Majesty took a fancy to him—perhaps because he, like the king himself, was a Hanoverian—appointed him his astronomer and gave him a house near Windsor in which to erect his telescope and make his observations. The salary attached to the office being only £200 per annum, Herschel had to eke out his income by making telescopes for sale, a hopeless waste of time for a man of his ability. With the aid of influential friends, however, his circumstances began to improve The king was induced to bear the cost (£4,000) of a new and much larger telescope, and, with this instrument, Herschel pursued his labours. Results were soon forthcoming. Two new satellites were discovered for Saturn in addition to the five already known, Uranus was

[illegible] 1822

[illegible]

also provided with tw[illegible]
[illegible]
[illegible], Hersch[illegible]
[illegible]

greatly improved; but the altered domestic circumstances necessitated a daily separation from his sister, to the sorrow of both. The family now removed to a much more commodious house at Slough, where they remained till Herschel's death in 1822.

The work accomplished during those years was prodigious. In addition to the hundreds of mirrors he had manufactured with his own hands, he contributed nearly seventy memoirs to the Royal Society, recording no less than 2,500 nebulæ and over 800 double stars, *i.e.* stars that appeared to revolve round each other. But his most astounding discovery was that the sun and the whole planetary system was itself moving through space! If one walks along a very lengthy straight street, the opposite lines of houses at the extreme end appear to be almost touching each other, but as one gradually approaches the end they appear slowly to move apart; and on looking backwards the pedestrian sees the houses behind him closing together. Of course the separation and approximation are only apparent; the movements are really due to the traveller's own motion to and away from the ends of the street. Similarly, Herschel detected a gradual widening between certain stars in the constellation of "Hercules," and, grasping the significance of this, boldly asserted that our whole solar system was moving through space towards this constellation.

Thus it is to the whilom bandsman of a regiment of the Hanoverian Guards that we owe what has been well termed "a science of the stars." "Hitherto the stars had only been observed for nautical and practical purposes. Their times of rising and southing and setting had been noted; they had been treated as a clock or piece of dead mechanism, and as fixed points of reference. All the energies of astronomers had gone out towards the solar system. It was the planets that had been observed. . . . But for the stars, the old Ptolemaic system might still have been true. They might still be mere dots in a vast crystalline sphere, all set about one distance, and

subservient to the uses of the earth. Herschel changed all this. Instead of sameness he found variety; instead of uniformity of distance, limitless and utterly limitless fields and boundless distances; instead of rest and quiescence, motion and activity; instead of stagnation, life." (Lodge.)

In 1792 there was born to the great astronomer a son, John, who, though also a distinguished searcher of the heavens, is somewhat eclipsed by his giant father. Sir John Herschel, as he ultimately became, did for the southern hemisphere, at the Cape of Good Hope, where he built an observatory, what Sir William had done for the northern, and also greatly extended our knowledge of double stars, of which he catalogued over 2,000. He did much also to popularize the study of the heavens by writing a famous treatise called *Outlines of Astronomy*.

Herschel's discovery of Uranus in 1781 was an event of the first importance, and it was only natural that astronomers should have watched the new planet with extreme care with the view of tracing its orbit and seeing whether it also obeyed the Newtonian laws of gravity. As the years passed by, and as the quality and accuracy of astronomical instruments improved, it became apparent that Uranus was not behaving itself quite as, theoretically, it ought to. It was constantly altering its course, and these irregularities or perturbations attracted considerable attention. One young Cambridge undergraduate, named JOHN COUCH ADAMS, vowed he would try and solve the problem as soon as his examinations were over It took him two years to work out the calculations necessary, but in October 1845 he wrote to the Astronomer Royal stating that the eccentricities of Uranus could be accounted for only by assuming the existence of yet another planet outside its orbit. The Astronomer Royal, Sir George Airy, put certain questions to young Adams, but he did not reply, and so the communication was pigeon-holed

Meanwhile another brilliant mathematician this t[illegible] a Frenchman named LEVERRIER, who had been w[illegible]

on the same problem unknown to Adams, published a paper in June 1846, stating precisely where the unknown stranger that was upsetting the movements of Uranus would be found. This paper woke Airy up, for he recognized that the Frenchman had calculated the position of the disturber to be within 1° of where Adams, eight months before, had prophesied it would be found. Wherever the somnolence lay, it was not at Berlin, for when Leverrier wrote to Galle, the head of the observatory in that city, telling him where exactly to look for the stranger, Galle, that very night, swept the sky in the vicinity, and, sure enough, there it was! The new planet was christened "Neptune." One cannot help feeling that there must have been some heartburnings in Cambridge and at Greenwich when the truth was made known to the world.

We have seen how Rœmer made an attempt at measuring the distance of the sun from the earth, and arrived at an approximate result from observation of its parallax, and also how Bradley followed in his footsteps until he was switched off by the problems of aberration and nutation. These stupendous distances still remained undetermined. Technically the parallax of a star is the angle made at the star by two lines drawn from the ends of the radius of the earth's orbit. Obviously the farther away the star is the smaller will be the angle, until, when the star is at an infinite distance the angle will be nil. But since the star is visible it must be at a finite distance, and so there must be an angle, however minute. The measurement of such angles obviously required instruments of much greater precision than any that Rœmer or Bradley possessed. The feat of measuring such angles was at last accomplished by Bessel, the astronomer in charge of the observatory at Königsberg, with the aid of an instrument called a heliometer, constructed for him by an optician of Munich, named Fraunhofer, of whom more anon. Without going into either the structure of the instrument or into Bessel's methods, it may be said that, making his observations on a star known as 61 Cygni, he arrived at a parallax of one-third

of a second of arc. (A second of arc means $\frac{1}{3600}$ of a degree, and the second has no reference at all to time.) Bessel was nearly, but not quite, right, for, with still more exact instruments, the parallax has been found to be closer to one half-second. A distinguished modern physicist (Sir Oliver Lodge) has given us some useful and homely comparisons to help us to appreciate these measurements. Half a second of arc "is the angle subtended by 26 feet at a distance of 2,000 miles. If a telescope planted at New York could be directed to a house in England, and be then

have turned through half a second, the angle of greatest stellar parallax. Or, putting it another way. If the star were as near us as New York, the sun, on the same scale, would be nine paces off. As 26 feet is to the distance of New York, so is 92 millions of miles to the distance of the nearest fixed star. Suppose you could arrange some sort of telegraphic vehicle able to carry you from here to New York in a tenth part of a second . . . such a vehicle would carry you to the moon in twelve seconds, to the sun in an hour and a quarter. Travelling thus continually, in twenty-four hours you would leave the last member of the solar system behind you, and begin your plunge into the depths of space. How long would it be before you encountered another object? A month, should you guess? Twenty years you must journey with that prodigious speed before you reach the nearest star, and then another twenty years before you reach another. At these awful distances from one another the stars are scattered in space, and were they not brilliantly self-luminous and glowing like our sun, they would be hopelessly invisible."

The brain truly reels in its effort to conceive such stupendous distances, and yet astronomers are confident that beyond all that our mightiest telescopes can help us to discern there are yet more and ever more stella
and so on without end

" Below lay stretched the boundless universe !
  There, far as the remotest line
That limits swift imagination's flight,
Unending orbs mingled in mazy motion,
  Immutably fulfilling
  Eternal Nature's law.
  Above, below, around,
  The circling systems formed
  A wilderness of harmony—
  Each with undeviating aim
In eloquent silence through the depths of space
  Pursued its wondrous way."

SHELLI

Although the eighteenth century ended in a catastr for chemistry in the criminal execution of Lavoisier, new century was bright with promise, for the last dec of the eighteenth saw the birth of men like Dalton, founder of the atomic theory, Gay-Lussac, the disco of the law of combination of gases, Davy, whose nan famous in connection with electro-chemistry and the mi safety-lamp, and the greatest of them all, Faraday, to w modern electricity owes its pre-eminence both in ph and chemistry. All of these, save Dalton, were mere yo when the century was born ; Faraday, indeed, was a of nine.

We have already seen how men like Boyle and Caven did not confine themselves to chemical research, but n important discoveries in physics also ; and as the y pass on we shall find it ever more and more difficul separate the one science from the other. Indeed, it ma said that advance in one is conditional on advance in other.

While Herschel, Bessel and Adams were investiga the mysteries of the infinitely great, Dalton and his temporaries were probing the secrets of the infinitely s for it is with the atomic theory of matter that Dalton ch concerned himself. Atoms, it is true, have come to r almost miniature solar systems at the present day, but electron theory and all that it signifies is beyond the view of this book, and, moreover, the whole subject is on

JOHN DALTON, 1766–1844.
(From a mezzotint by C. Turner after Lonsdale.)

its infancy. Meanwhile we may give some attention to the conception of the composition of matter that held sway and did good service for nearly a century.

JOHN DALTON was born in 1766 near Cockermouth, in

Cumberland, of Quaker parents. His father was a hand-loom weaver in poor circumstances, although he added to his income by farming a small plot of land. John was educated at first at the village school, but in 1781 became a sort of pupil-teacher at his brother's school in Kendal, where he remained for twelve years. During this period he kept meteorological records and also studied the plants and insects of the district. At the end of his stay in Kendal he went to Manchester to be science tutor at New College (the embryo of what became Manchester College, Oxford). In this city he remained for the rest of his life, devoting himself to private tuition, after six years of work at the college. He finally made his home with a clerical friend, and, for twenty-five years, spent a quiet and uneventful life, broken only by a visit to Paris, where he met some of the leading French scientists. His declining years were made easier for him by the grant of a Civil List pension of £300 a year, more than ample to meet his extremely modest wants. Later on there were indications that he, as so many other distinguished men of science in the past, was suffering from incipient paralysis. A first attack in 1837 was the beginning of the end, for a second proved fatal, and he passed away peacefully on July 27, 1844.

Dalton's atomic theory may perhaps be best expressed in his own words. "Every particle of water is like every other particle of water; every particle of hydrogen is like every other particle of hydrogen. When any body exists in the elastic state, its ultimate particles are separated from each other to a much greater distance than in any other state; each particle occupies the centre of a comparatively large sphere, and supports its dignity by keeping all the rest, which by their gravity, or otherwise, are disposed to encroach upon it, at a respectful distance. . . . Chemical analysis and synthesis go no farther than to the separation of particles one from another, and to their reunion. No creation or destruction of matter is within the reach of chemical agency. . . . All the changes we can produce consist in separating particles that are in a state of cohesion

or combination, and joining those that were previously at a distance."

The long series of analyses of chemical substances, made after the introduction of quantitative methods by Lavoisier, led to the conclusion that every chemical compound always contained the same constituents combined in the same proportions. This was the law established by the French chemist, Proust. Dalton went a step farther, and showed that each constituent or element had a fixed weight, and combined with other elements in definite multiples of this weight. Thus a given weight of oxygen was found to combine with nitrogen in five different proportions, forming five distinct substances. Two volumes of nitrogen united with 1, 2, 3, 4, or 5 volumes of oxygen, giving the five substances known respectively as nitrous oxide, nitric oxide, nitrous acid, nitric peroxide, and nitric acid. Further, if hydrogen, being the lightest substance known, be represented by 1, oxygen, being sixteen times as heavy as hydrogen, had the atomic weight 16, then the combination of oxygen with other elements always took place in multiples of 16. For instance, 16 volumes of oxygen would unite with 12 volumes of carbon to form carbon monoxide, or 32 volumes of oxygen with 12 volumes of carbon to form carbon dioxide. Each element had its own combining weight. This is known as the "law of [illegible] cuous dis- [illegible] mposed of atoms was no new one. It was as old as Democritus, the "laughing philosopher" of Abdera, five centuries B.C., who held that everything was composed of invisible and indivisible particles or atoms. To Dalton the atom was more than a particle, it was a particle that possessed a definite weight, and hydrogen, being the lightest known substance, was represented by unity. When two elements united, their atoms could not be split; there must be at least one atom of each element in the compound, and the smallest possible quantity of the combine was a molecule. Thus

one atom of oxygen united with two atoms of hydrogen gave a molecule—the least possible particle—of H_2O, water, *i.e.* $HO_{\frac{1}{2}}$, could not exist. In a word, an atom, according to Dalton, was the smallest amount of any element that could unite with any other element.

If, as modern chemists and physicists tell us, the atoms are themselves compounds of protons and electrons, the Daltonian hypothesis must be given up, but it served its purpose at the time, and to it we owe, in large measure, the development of chemistry during the nineteenth century.

One can scarcely imagine a greater contrast than that between the simple, quiet, unambitious, almost humdrum Quaker, Dalton, who, we learn, was no conversationalist in private nor orator in public, and a clumsy and ill-trained experimenter, and the cultured society favourite, the eloquent lecturer and brilliant experimentalist, Sir HUMPHRY DAVY.

Davy was born in Penzance in 1778, and educated there and afterwards at Truro, but on his father's death he returned to his native town to become an apothecary under a Mr Borlase, who seems to have been a man of attainments and insight superior to those of the average country practitioner of the time.

In 1797 Davy began the serious study of natur science, and in chemistry he set himself to mast Lavoisier's *Traité de Chimie*, and at the same time ma experiments with the apparatus and materials he fou in Mr. Borlase's surgery. It was during this period made the acquaintance of a Dr. Beddoes of Bristol, had established in that city a medical institute, the pur of which was to inquire into the medicinal values of g and for that reason called the "Pneumatic Instituti Beddoes had been so impressed with the ability o young chemist that he invited him to become superinte of the Institution, and Borlase, not wishing to sta Davy's way, released him from his apprenticeship end of 1798.

SIR HUMPHRY DAVY.
(From a pastel made from life by James Sharples. By permission of the Bristol Gallery of Art.)

One of the first investigations he undertook at Bristol was the determination of the effect on the human body of the inhalation of certain gases, and one of these was nitrous oxide, popularly called "laughing gas," and now

a well-known anæsthetic. This gas had then an evil reputation as a "principle of contagion when respired by animals in the minutest quantities," but Davy took the risk and inhaled sixteen quarts of it in seven minutes. Instead of experiencing any evil effects, he found it made him "absolutely intoxicated," so much so that he felt compelled to express his feelings in verse! His experiments with other gases were not always so pleasant or exhilarating, as we may well imagine when we learn that among them were marsh gas (carburetted hydrogen or fire-damp) and carbonic acid.

In 1801 Davy was offered the post of lecturer on chemistry at the Royal Institution by Count Rumford, to be elevated in due course to a professorship at £500 per annum. It was here that he carried out the researches that made his name so famous, and it was here also that he trained a youthful assistant who was destined to be his successor and an even greater man than himself—Michael Faraday.

His first work at the Royal Institution was the preparation and delivery of a course of lectures on Agricultural Chemistry, and in these he was so successful that the course was repeated every year until 1813. At the same time he began to study the electrical phenomena that had been the subject of investigation by the two Italian physicists Galvani and Volta, professors in Bologna and Pavia respectively. GALVANI had found that the leg of a dead frog could be made to jerk when placed in the neighbourhood of an electrical machine, and that when a leg was suspended by a copper hook on an iron balcony a similar convulsion took place every time the free end of the leg touched the iron. This became known as "Galvanism," and Galvani assumed that there must be some fluid in the leg which circled round every time the leg touched the two metals. VOLTA, on the other hand, showed that the electricity was not in the leg, but was produced by the contact of the copper and the iron through the moist leg. He was thus led to construct

Facing page 176.

MICHAEL FARADAY.

(From a [illegible])

what is known to this day as a Voltaic battery, consisting of one or more cells containing strips of zinc and copper plunged in acidulated water. About the same time Nicholson and Carlisle accidentally discovered that when the two terminals from such a battery were passed into water, bubbles of gas arose from each terminal, one of which was oxygen and the other hydrogen, while an acid was produced at the positive pole and an alkali at the negative one.

Davy, after a long series of experiments, succeeded at last in decomposing water into its constituent elements by using vessels that were not affected by the electric current. Subsequent efforts with potash and soda resulted in the decomposition of these bodies, hitherto regarded as elements, and in the discovery of the metals potassium and sodium. Thus was initiated the now well-known method of chemical analysis called electrolysis, and by its means several new elements were brought to light both by Davy and by the Swedish chemist Berzelius. Davy's view, as expressed in his own words, was that "hydrogen, the alkaline substances, the metals, and certain metallic oxides are attracted by positively electrified metallic surfaces, and repelled by negatively electrified metallic surfaces; and these attractive and repulsive forces are sufficiently energetic to destroy or suspend the usual operation of elective affinity."

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he gave the name of chlorine. This discovery led him to believe that fluoric bodies were compounds, and he suggested the name fluorine for the element he believed to be present in them, although he was not successful in actually isolating it. This was effected in 1887 by the French chemist, Moissan. With the assistance of a gigantic Voltaic battery he made another and very notable discovery, viz. that when two charcoal terminals were approximated, a brilliant light was produced between them, a result which led to the invention of the arc lamp

In 1812 Davy was knighted by the Prince Regent, and about the same time resigned his professorship, but retained the title of Honorary Professor and Director of the Laboratory. In March 1813 Faraday had become an assistant at the Royal Institution, and in the autumn of that year Davy and his wife, accompanied by Faraday, left England for an extended tour over the Continent, during which he had the opportunity of meeting Gay-Lussac, Berthollet, Cuvier, Volta and other distinguished scientists.

On his return to England he was led to make researches on flame which resulted in the invention of the miner's safety-lamp, with which his name is universally associated. He discovered "that explosive mixtures of mine-damp will not pass through small apertures or tubes; and that if a lamp or lanthorn be made air-tight at the sides, and furnished with apertures to admit air, it will not communicate flame to the outward atmosphere." When urged by his friends to patent his discovery and so obtain substantial royalties, Davy refused (page 108). He did, however, receive a baronetcy, and also a service of plate which was presented to him by the grateful colliery owners.

During another continental visit he was elected President of the Royal Society in succession to Sir Joseph Banks, and maintained the chair with great dignity and éclat until 1827 when, his health having given way, he resigned. Another visit to the Continent followed, but it was his last, for he died at Geneva on May 29, 1829, at the early age of fifty-one, and was buried in the cemetery there. On his monument are engraved the words:

"SUMMUS ARCANORUM NATURÆ INDAGATOR."

An American contributor to *Silliman's Journal* expresses a true estimate of his worth: "His reputation is to[o] intimately associated with the eternal laws of nature t[o] suffer decay, and the name of Davy, like those of Arch[i]medes, Galileo, and Newton, which grow greener by tim[e] will descend to the latest posterity."

The Royal Institution, which was founded by Count Rumford, had for its object the diffusion of knowledge with regard to "useful mechanical inventions and improvements, and for teaching by courses of philosophical lectures and experiments the application of science to the common purposes of life," and we have seen how, under Davy's fostering care, it became the centre of scientific research in England. The mantle of the great "arcanorum naturæ indagator" fell on the shoulders of his youthful assistant, MICHAEL FARADAY.

Faraday came of a Westmorland stock, his father being a blacksmith of Kirkby Stephen, who subsequently removed to London. Michael was the third child of the marriage, and was born on September 22, 1791. At the age of thirteen he became an errand boy in a stationer and bookbinder's shop. In 1812 a customer of his employer took young Faraday to hear Sir Humphry Davy lecture at the Royal Institution, where the future professor made careful notes of the lectures, supplemented by drawings of the apparatus used. These he sent to Davy, who, with his customary kindliness, invited him to an interview, which resulted in Faraday's being appointed assistant at twenty-five shillings per week and free rooms in the Institution buildings. As we have seen, Faraday accompanied Davy on his continental travels, but whatever pleasure they may have given his patron, they do not seem to have raised any enthusiastic response in the mind of his secretary, for he wrote to a friend from abroad: "I fancy that when I set foot in England I shall never take it out again; for I find the prospect so different from what it at first appeared to be, that I am certain if I could have foreseen the things that have passed I should never have left London." Later on, in a letter to his mother, he finished by saying: "At Ostend we embark, and at Deal we land on a spot of earth which I will never leave again." In this case his intuition, for once, was at fault, for on two occasions, many years later, he spent several months on the Rhine and in Switzerland.

In 1821 he married and took up his abode in the Royal Institution, with an improved status and increased income. During the years preceding and following this event he wrote papers on a variety of subjects, but all the time he was meditating on the work accomplished by Oersted and Ampère on the relation between magnetism and electricity. Ever since the fourteenth century it had been known that a needle rubbed with a loadstone and left free to swing pointed north and south, and after Volta and others had shown that electric currents were constantly passing through the air, the question arose as to whether these currents were in any way connected with the mysterious properties of the magnetized needle. Light was at length thrown on the subject by Oersted, professor of physics in Copenhagen, who, in 1819, discovered that an electric current passing near a magnetized needle caused the latter to place itself at right angles to the path of the current. Ampère's contribution to the subject consisted in showing that the direction in which the needle pointed depended on the direction in which the current flowed. He further discovered that the north pole of one needle repelled the north pole of another needle, but attracted its south pole, and vice versa. From these data Ampère argued that if two rods be suspended so that both were free to move, they would be attracted when the current was sent through both in the same direction, and repelled when the current was sent through one rod in one direction and through the other in the opposite direction. From this Ampère arrived at the idea of magnetizing a metal bar by sending an electric current through it. This he did by winding an insulated wire round a steel rod and connecting the ends of the wire with the positive and negative poles of a battery. The result was entirely successful.

Now Faraday comes on the scene. He showed, conversely, that when a magnet was brought near a coil of wire a current of electricity was generated in it, but that when the magnet was removed the current in the wire was reversed. This was the basic principle of the induction

coil used in every physical and physiological laboratory at the present day. Obviously, if a magnet were made to revolve rapidly near such a coil a supply of electricity would be generated, and it is on this idea that the electric dynamo is constructed. To Faraday also we owe the terminology in electricity now in use, such as electrode, electrolyte, electrolysis, anode, cathode and ion.

Another line of research resulted in the discovery of the influence of a magnetic field on polarized light, while at an earlier date, by the combined application of pressure and cold to gases, he successfully reduced many to the liquid condition. To this subject he gave renewed attention in 1845, although it was left for Pictet and Cailletet, thirty years later, to reduce the gases of the atmosphere to the liquid condition.

In the closing years of his life he carried out much research work for the Trinity House Commissioners, and was instrumental in getting the magneto-electric light ... ished ... er he ... just waiting." He passed quietly away, sitting in his chair, on August 25, 1867.

> "Was ever man so simple and so sage,
> So crowned and yet so careless of a prize?
> Great Faraday! who made the world so wise,
> Who loved the labour better than the wage"

On one occasion, about the middle of the eighteenth century, so the story goes, the professor of physics in Glasgow University, John Anderson, discovered that a model engine in the physical department was out of repair. He thereupon took it to the university workshop, then in the charge of a man who had been appointed as instrument-maker to the university. This man was JAMES WATT, often called the "inventor of the steam engine." Steam engines, however, were known and used long before Watt's time—in fact, it was a model of such an engine that he was

invited to repair, the invention of a blacksmith called Newcomen, a native of Dartmouth. The famous physicist, Bunsen, to whose work we shall have occasion to refer later on, says: "There are two distinct classes of men—first, those who work at enlarging the boundaries of knowledge, and, secondly, those who apply that knowledge to useful ends." Watt was one of the second class, but his invention had so much of pure science in it that his name cannot be omitted from such a sketch as the present.

He was born at Greenock on January 19, 1736, the son of a tradesman who had lost all he possessed in speculation. Watt, thus early thrown on the world to make his own living, selected the trade of instrument maker, and spent a year in London as an apprentice. On his return to Glasgow the guild or trade-union of those days prevented him from opening a shop in the city, but the university provided him with a workroom and apparatus, and, in 1757, conferred on him the appointment above mentioned.

To return to the damaged model, it is essential, in order to understand Watt's invention, to grasp the principle on which Newcomen's machine operated. "In Newcomen's engine the cylinder stood vertically under one end of the main lever or 'beam,' and was open at the top. Steam, at a pressure scarcely greater than that of the atmosphere, was admitted to the under side; this allowed the piston to be pulled up by a counterpoise at the other end of the beam. Communication with the boiler was then shut off, and the steam in the cylinder was condensed by injecting a jet of cold water from a cistern above. The pressure of the air on the top of the piston then drove it down, raising the counterpoise and doing the work. The injection water and condensed steam which had gathered in the cylinder were drained out by a pipe leading down into a well" (Ewing). The fundamental flaw in this machine was that at every movement of the piston the cylinder and its contents had to be cooled down, so that three-quarters of the heat of the new supply of steam was wasted in reheating the cylinder.

At this time Black, the discoverer of carbon dioxide, was professor of chemistry at Glasgow, and a friend of Watt. He was engaged on his researches on latent heat, and to him Watt went with his problem. Watt's idea was that "as steam is an elastic body it will rush into a vacuum, and if a communication were made between the cylinder and an exhausted vessel it will rush into it and might there be condensed without cooling the cylinder." By an ingenious arrangement of valves Watt was able to get rid of air pressure altogether and introduce steam alternately above and below the piston, while condensing the steam in an independent cylinder. His first patent was taken out in 1769, but in the four years that had elapsed since he had completed his model he had maintained himself by surveying work. But after this time he was greatly aided by a Birmingham engineer called Boulton, who owned large engineering works near that city. The partnership was an ideal one, for Boulton supplied the funds and ran the commercial side of the work, while Watt supplied the inventive brains. The application of Watt's invention, with all its numerous improvements, to all sorts of machinery, both stationary and locomotory, is a development of the nineteenth century, and its consideration would take us out of the realm of pure science into that of applied, with which we are not concerned. The basal idea of Watt's invention, however, is contained in his friend Black's researches on latent heat, of which it was the direct outcome.

His life came to a peaceful close at his house near Birmingham on August 19, 1819, when he had just reached his eighty-third year.

Reference has just been made to Black's doctrine of latent heat, *i.e.* heat lost when a solid is turned into a liquid or a liquid into a gas. It must be remembered that heat was in earlier times believed to be a kind of fluid which had received the name of "caloric"; but that heat was not a fluid was first proved conclusively by Count RUMFORD, who succeeded in boiling water by rapidly

drilling a cylinder of gun-metal under water, and also by Davy, who melted ice by friction. From these initial experiments it became apparent that, as Davy expressed it, "heat is a peculiar motion, probably a vibration of corpuscles of bodies, tending to separate them." These observations led to the conclusion that energy of whatever kind could be converted into heat, and the problem to be solved in the first instance was what was the mechanical equivalent of heat? This was ascertained by JAMES PRESCOTT JOULE (1818–89), a pupil of Dalton in Manchester. By means of a simple piece of apparatus he was able to show that water could be raised in temperature by the expenditure of mechanical energy, and, after allowing for various necessary corrections, he estimated that about 772 foot-pounds of mechanical work were required to raise the temperature of one pound of water one degree. (The number given by later research is 778 foot-pounds, a foot-pound being defined as the energy required to raise one pound weight one foot.) Conversely, for every degree Fahrenheit added to the temperature of one pound of water energy had to be expended that would raise a weight of one pound to a height of 772 feet.

Upon this law is based one of the most fundamental axioms of physics, viz. that the total amount of energy in Nature is a constant. One form of energy may be transformed into another, but it cannot be created and it cannot be destroyed. It may be stored up as potential energy—hidden, but capable of being released and then of performing work, or it may be kinetic—active, visible, when actually doing work. This law of the conservation of energy was enunciated most clearly in 1847 by HERMANN VON HELMHOLTZ, who ultimately became the renowned professor of physics in Berlin University, and who was one of the foremost men of science in the nineteenth century. "We cannot create mechanical force," he said, "but we may help ourselves from the storehouse of Nature. The brook, the wind, which drive our mills, the forest, the coal bed, which supply our steam engines and warm our rooms, are the

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LORD KELVIN

(From a painting by F. T. King in the National Portrait Gallery.)

bearers to us of a small portion of the great natural supply which we draw upon for our purposes."

But this "storehouse of Nature" does not constitute an inexhaustible supply. In Newcomen's engine three-quarters of the heat was wasted, and even in Watt's machine there was still a loss, although not nearly as great. It would be more correct to describe this loss as wasted energy, since no energy is ever "lost." Every time one form of energy is converted into another there is a waste in the form of heat, which becomes dissipated into space, and therefore becomes unavailable for any further purpose.

This constant dissipation of energy was first emphasized by one of our most distinguished physicists, the late Lord Kelvin, in 1852. WILLIAM THOMSON was born in Belfast in 1824. His father was professor of mathematics at Glasgow University, and by him Thomson was educated privately. After completing his studies at Cambridge, he became professor of natural philosophy at Glasgow, a post he held for fifty-three years. It would lead us too far into modern times to attempt any summary of the work accomplished by this remarkable man. We must content ourselves by noting that his first great achievement was the elaboration of the dynamical theory of heat, in the course of which he enunciated the doctrine of the dissipation of energy just alluded to. In 1854 he became a prominent telegraphist, and invented many instruments connected with the measurement of electricity, such as the mirror galvanometer, the electrometer and the siphon recorder At a later date he improved the mariner's compass, and invented the sounding machine. With regard to the last-mentioned instrument a bluejacket was once heard to remark: "I don't know who this Thomson may be, but every sailor ought to pray for him every night."

Kelvin died at the advanced age of eighty-three, in 1907

We must bring to a close this very incomplete sketch of some of the great advances made in the nineteenth century

by referring to an entirely different subject of immense importance, not only in physics, but also in chemistry and astronomy, viz. spectrum analysis.

Bessel, who, it may be remembered, attempted to measure the distance of the "fixed stars," was aided by the use of an instrument known as a heliometer, constructed for him by an optician of Munich, named JOSEPH FRAUNHOFER. This man was the son of a glazier, born in Bavaria in 1787. Owing to the collapse of a house in which he lived, he was badly injured when a lad of fourteen, and attracted the attention of the Elector of Bavaria, who happened to be an eye-witness of the accident. The Elector gave him a sum of money sufficient to release him from his apprenticeship to a mirror manufacturer, and he thereafter supported himself by making and polishing spectacle and other lenses, incidentally studying physics and astronomy. Working on the lines of Wollaston, who was the first to detect dark lines crossing the colour band of the spectrum, Fraunhofer investigated this phenomenon with great care, identifying over five hundred of them, and concluded that sunlight must be deficient in the rays which were represented by the dark lines. Since his time these dark bands have been always known as "Fraunhofer's lines." Light from the moon and from the planet Venus gave the same dark bands, but light from the fixed stars gave quite different spectra. He logically concluded that the differences must be due to the nature of the light emanating from these suns and not to the absorbent effect of the earth's atmosphere.

This new line of research was to a large extent neglected until Sir John Herschel—son of the great astronomer—Sir David Brewster, who became principal of Edinburgh University, and others started examining the light produced by certain combustible bodies. As a result of their researches it was found that every incandescent gas had its own dark lines in the spectrum, no matter how many other gases were present as well. The vapour of sodium, for instance, could always be recognized by a bright yellow

streak opposite Fraunhofer's line D, hydrogen by streaks opposite lines C, F and G, and so on. By careful observation of these lines new metals were rapidly discovered, especially by Bunsen and Kirchhoff, who identified the metals cæsium and rubidium, and by Crookes, who discovered thallium, in both cases about the year 1860.

The spectroscope now became a recognized instrument in chemical analysis, and in the hands of Bunsen and Kirchhoff was an apparatus of the utmost value in the identification of the elements. Kirchhoff found that when a ray of sunlight was passed through the luminous vapour of sodium, the yellow streak of the sodium flame coincided exactly with the dark band D of the solar spectrum, and similarly with other metals and non-metals, and hence he arrived at the conclusion that every incandescent gas absorbed out of white light just those rays that it gave out itself when glowing. It was thus possible to identify *gases in the atmosphere of the sun. Sir William Herschel* regarded the sun as a dark body surrounded by a luminous atmosphere, but spectrum analysis has taught us that it is a luminous body enveloped by incandescent vapours.

The next step was taken by Sir William Huggins, when the spectroscope was made to unravel the chemistry of the stars. It showed that, while some of them contained in their atmospheres the same elements that we are familiar with on earth, others exhibited absorption bands that represented no known substance. Helium, for instance, was detected in the sun in 1868 by Lockyer, and it was not till 1895 that it was found on the earth by Ramsay while engaged on his researches on atmospheric gases. Other stars, again, seemed deficient in bodies which were quite common on our planet Thus the great star, Betelgeuse, possesses no hydrogen, and the sun itself appears to be without several elements which are to be found in every chemical laboratory.

Thus from the investigation of the infinitely small, the Daltonian atom and the modern electron, we are brought back to the infinitely great, the giant suns that look down

on us from distances almost incalculable and certainly inconceivable.

"Then the angel lifted up his glorious hands to the heaven of heavens, saying, 'End there is none to the universe of God. Lo! also, is there no beginning!'" (RICHTER).

CHAPTER IX

THE FOUNDERS OF BIOLOGY

BEFORE we consider those who may be termed the founders of biology, it is essential that we should obtain a clear conception of what is understood by the term biology. The word is of quite recent origin, for it was used for the first time by a German naturalist called Treviranus. It occurs in the title of a book, *Biology, or The Philosophy of Living Nature*, published by him in the very early years of the nineteenth century (1802–5), and the point of special importance for us lies in appreciating that this comparatively new science deals with *living* things. It is the science that deals with live organisms, not merely with their corpses, it is the science that watches the machine at work, not simply studies the component parts when the machine comes to a standstill, for that would be more appropriately called necrology. A study of the form and structure of, say, a chronometer, must be accompanied by a study of its action, of the manner in which each constituent part co-operates in the performance of its functions. If this be true of apparatus relatively so gross, how much more so of the infinitely more complex and delicate mechanisms known as plants and animals In order to understand what a plant or an animal really is we must study not only the *morphology* of its various parts, with the extensions of morphology, *anatomy* and *histology* but also its *physiology*. There are, however, several other lines of inquiry that may be followed out with interest and profit. There are problems connected with the relation of the organism to its environment, a comparatively new

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sub-science, known as *ecology*; its occurrence on and its migrations over the earth's surface—*distribution*; and its genealogical relationship to other organisms obviously allied to it—*taxonomy* and *phylogeny*—whether these be now living or represented by more or less perfectly preserved remains embedded as fossils in the earth's crust.

Biology in the widest sense of the term—the scientific study of living things—had its foundations laid in the very remote past, but, in its more restricted sense—the study of vital phenomena—it is a development of the last three hundred years. The systematic collection, investigation and classification of animals and plants were undoubtedly initiated by Aristotle and his pupil Theophrastus, more than three hundred years B.C., and even these early naturalists made some crude attempts at unravelling the mysteries of life, more especially of the origin of organisms, the embryology of the animal and the germination of the seed; but after them nothing further of any importance was accomplished for two thousand years. The only exception was in relation to medicine, where men like Galen were led to inquire more particularly as to the structure of the human body by comparing it with those of the lower animals, and to investigate more carefully as to the "vertues," as they were termed, of plants that might cure a malady or heal a wound. It is not until the sixteenth century that scientific interest in organisms, for their own sakes and not for what could be got out of them, was reawakened, and it is therefore to that period that we must turn our attention if we are to watch the birth of the modern science of biology.

The name that stands out most prominently in this early period is that of ANDREAS VESALIUS, for not only was he the first real investigator of the structure of the human body, but he was also the first biologist to overthrow belief in written authority and to insist on observation and common sense as the only true guides to knowledge. He was born in Brussels on December 31, 1514, and studied at the ill-fated university of Louvain. From there he went to Paris

to work under Sylvius, an anatomist of some repute, who, although he adhered to the time-honoured method of discoursing on Galen and other ancient authorities, did attempt to illustrate his lectures by dissections of animals, carried out for him by surgeon barbers of the city. Vesalius scandalized these worthies, it is said, by pushing them aside and showing them how dissections ought to be made. Leav-

Michael Foster, the late distinguished professor of physiology in the university of Cambridge "He at once began to teach anatomy in his own new way. Not to unskilled, ignorant barbers would he entrust the task of laying bare *before the students the secrets of the human frame*; his own hand, and his own hand alone, was cunning enough to track out the pattern of the structures which day by day were becoming more clear to him. Following venerated customs, he began his academic labours by 'reading' Galen, as others had done before him, using his dissections to illustrate what Galen had said But, time after time, the body on the table said something different from that which Galen had written

"He tried to do what others had done before him—he tried to believe Galen rather than his own eyes, but his eyes were too strong for him, and in the end he cast Galen and his writings to the winds, and taught only what he himself had seen and what he could make his students see, too. Thus he brought into anatomy the new spirit of the time, and the men of the time, the young men of the time, answered the new voice Students flocked to his lectures; his hearers amounted, it is said, to some five hundred, and an enlightened senate recognized his worth by repeatedly raising his emoluments.

"Five years he thus spent in untiring labours at Padua. Five years he wrought, not weaving a web of fancied thought, but patiently disentangling the pattern of the texture of

the human body, trusting to the words of no master, admitting nothing but that which he himself had seen; and at the end of the five years, in 1542, while he was as yet not twenty-eight years of age, he was able to write the dedication to Charles V. of a folio work entitled *The Structure of the Human Body*, adorned with many plates and woodcuts, which appeared at Basel in the following year, 1543."

It was not to be expected that a man of Vesalius's character should be permitted to speak thus freely, even in the enlightened city of Padua. The doctors opposed his teaching because it was contrary in fact to the authoritative utterances of Galen. The theologians opposed him because he both asserted and demonstrated that man possessed the same number of ribs on either side, and that consequently the manufacture of Eve from one of Adam's ribs was a fable. At length in despair he resigned his professorship and left Italy to become physician to Charles V. of Spain, where, however, although he became both renowned and wealthy, his enemies gave him no peace. The story goes that on one occasion he performed a post-mortem examination on a body which, it was averred, afterwards showed signs of life, and for this sacrilege he was condemned to undertake a pilgrimage to Jerusalem. On his return journey he was shipwrecked, and died on the island of Zante, in the Ægean, in 1564—a sorrowful ending to the career of a really great man. But the seed he had sown did not take long to germinate. Vesalius, though a splendid observer, lacked the "divine afflatus" that was essential to the transformation of the dead machine into the living entity. Where Vesalius explored and found new structures his great successor, Harvey, breathed into them the breath of life and showed the purpose of their being. The work of the anatomist is statical, that of the physiologist is dynamical, and the one is the complement of the other.

WILLIAM HARVEY was the son of a Kentish yeoman, the same sort of stock that bred the immortal Newton, and was born at Folkestone in 1578. He was educated

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WILLIAM HARVEY.

(From the painting by an unknown artist in the National Portrait Gallery.

first at Canterbury and, at the early age of fifteen, entered Caius College, Cambridge, and took his bachelor's degree when he was nineteen. In the following year he was attracted to the university of Padua, the scene of the triumphs of Vesalius, there to study under the great anatomist's successor, Fabricius, whose name is associated with the discovery of the valves in veins. In 1602 he graduated as M.D. in Cambridge and settled as a medical practitioner in London, at the same time giving lectures on anatomy ublished his famous *De Motu* Movements of the Heart and that this publication long post-dated his teaching on the subject, which had been carried on for many years previously, while Vesalius rushed into print when a young man of only twenty-eight. Harvey appears to have been in attendance on Charles I. at the battle of Edgehill in 1642, having sided with the Royalists, and after that retired to Oxford, where he lived for three years. During his absence from London his house was raided by the agents of the Parliament, and all his belongings, including his manuscripts and preparations, were destroyed. Abraham Cowley, the poet, in his elegy on Harvey bewails this loss in poignant terms:

> "O cursed war! who can forgive thee this?
> Houses and towns may rise again,
> And ten times easier 'tis
> To rebuild Paul's than any work of his."

In 1646 he returned to London where he lived in retirement, completing his researches on the embryology of the chick, which were published in 1651, under the title *Exercitationes de generatione*. Finally, he went to live in his ancestral home in Kent, where he died in 1657 at the age of eighty, another victim to paralysis, which, as we have already seen, —Boyle, Dalton and

discovery, it may be well to outline the views on the subject held by his

predecessors and contemporaries. Aristotle thought blood was manufactured from food in the liver, that it was carried from there to the heart, and thence distributed by veins throughout the body. According to the medical school of Alexandria the arteries were the transmitters of a subtle fluid or spirit, although Galen held that they also contained blood. That the blood itself moved was recognized, but the movement was regarded as casual and slow. It was asserted that there were two kinds of blood, one which flowed from the liver to the right ventricle, whence it passed to the lungs and other organs by the veins, and another kind which followed the same course by way of the arteries. The heart was believed to be divided into right and left sides by a porous partition that permitted an intermixture of blood from one side to the other. The heart itself expanded, but the expansion was due to some spirit within it, and even the presence of muscle in its walls was doubted.

Harvey, on the other hand, showed that the pulse was coincident not with the dilatation of the heart, but with its contraction. From the left ventricle arose a large artery which presently divided into an upper branch serving the head and neck, and a lower one serving the rest of the body. The blood from these two regions returned by two corresponding veins and entered the right auricle, thus completing the first or general circulation. The blood flowing from the left ventricle was bright scarlet, while that which flowed into the right auricle was dull purple. The reason for this change of colour and its relation to the gaseous contents of the blood was of course unknown in Harvey's time. From the right auricle the blood passed by an aperture guarded by valves into the right ventricle, by which it was pumped to the lungs, and returned from that organ by the pulmonary vein to the left auricle, and during its passage through the lungs regained its scarlet colour. From the left auricle it entered the left ventricle by a passage also furnished with valves, to recommence its journey through the body. Harvey thus established the fact that there were two circulations, a general and a pulmonary, that the

blood in the arteries and the veins was the same blood, and that the flow was constant, rapid and regular; finally, he showed that the active centre of operations was the heart and not the liver. Only in one respect he failed; the intercommunication between the final branches of the arteries and those of the veins was discovered by another biologist armed with an instrument, the microscope, which Harvey did not possess. This was Malpighi, who identified the capillaries in 1661, a few years after Harvey's death.

Harvey's work on embryology was not so successful. It was, indeed, impossible to arrive at any sound views on such matters before the facts had been studied microscopically, and it was not until the earlier decades of the nineteenth century that the whole story was elucidated. In Aristotle's time it was believed that the male provided the embryo and that the female only nourished it in its pre-natal condition. Galen thought both parents contributed something, and that the union of these two factors became the young animal. Harvey's contribution was more or less of a guess, but a correct one so far as it went, and to him we owe the famous aphorism, *Omne vivum ex ovo*—Every living thing comes from an egg.

The discovery of the circulation of the blood, commonplace as it seems to us now, was really an achievement of the first rank, and the fact that it was arrived at, as Harvey himself says, by watching the actual events in the living animal, stamps him as one of the first biologists in the true sense of the word.

We saw how in or about 1609 a Dutch spectacle-maker, called Lippershey, hit upon the association of lenses that developed in the hands of Galileo into the first telescope, and how that great man at once turned it to use in the examination of the celestial bodies. Similarly, another Dutch optician, Jansen, a few years earlier, got the idea of the simple microscope, an instrument much improved at a later date by Cornelius Drebbel, yet another Dutchman, who after many vicissitudes settled in England in the reign

of James I. Whatever improvements he may have carried out on the microscope, there appears to be little doubt that (according to Professor Joly) he was the first to invent "a ship in which one could row and navigate under water, from Westminster to Greenwich"—the first submarine, in short!

Of those who employed the microscope in their researches there are four whose names stand out pre-eminent, viz. Robert Hooke, Nehemiah Grew, Marcello Malpighi and Antony van Leeuwenhoek.

MARCELLO MALPIGHI was born in the village of Crevalcore, near Bologna, in 1628, the son of a small landed proprietor. After a good education, when he had just reached his majority, he found himself, on the death of his parents, burdened with the care of his seven younger brothers and sisters and the management of the family estate. A dispute arose between him and the proprietor of another estate which marched with his, called Sbaralgia. The dispute developed into a regular feud, and "representatives of the latter family followed him all his life with efforts to injure both his scientific reputation and his good name, but his best qualities showed under these persecutions, for he was dignified under abuse and considerate in his replies" (Locy).

At the age of twenty-five he graduated as M.D. in the university of Bologna, and three years later was called to a teaching post in Galileo's old university, Pisa. There he remained for three years, but his health, which had always been delicate, broke down, and he returned to his native city, only to incur once more the implacable enmity of the Sbaraglia clan. He taught with great success and éclat at Bologna until he was summoned to Messina, where he remained for four years, once more returning to Bologna in 1666. The rest of his life-story is soon told. In 1691 he became body physician to Pope Innocent XII., and died in Rome of apoplexy in 1694. His body was brought to Bologna and buried with the highest honours the city could bestow, and a public monument was erected in his

MARCELLO MALPIGHI, 1628–94.
(From the portrait by Tabor.)

memory. Thus in death, if not in life, the gentle naturalist triumphed over his hereditary foe.

The keynote of Malpighi's researches in the animal world was the idea that the fundamental facts with regard to the structure and physiology of the human body could be deduced from an examination of the corresponding

had no conception of the part it played in plant nutrition The movements of plant organs, such as the folding together of leaves at night, the coiling of twiners and tendrils, and so on, Grew explained on purely physical grounds, for the belief that *planta est corpus vivens non sentiens* was a dogma that no one challenged. The occurrence of sex in plants was not investigated by him, although he hesitatingly conceded that it might exist.

Malpighi's conception of plant anatomy closely resembled that of Grew, but his work is, if anything, more careful and exact; and throughout there is an attempt to give physiological explanations of the structures he describes. For instance, he regarded the leaf as a digestive organ, the digestion consisting of a sort of fermentation, while the sun's heat helped to "evaporate that which is of no service. For this purpose Nature has provided the leaves with numerous special glands for the sweating forth and gradual elimination of moisture, so that the sap, being thereby condensed, may be the more readily digested in the leaves."

Both writers gave a fairly accurate idea of the structure of the fruit, seed and embryo, and followed the stages in the germination of the seed with considerable skill.

But it is obvious from a perusal of these two classics that botanical science had a long way to travel before reaching the level of the sister science of zoology; still, the ground was broken and the seed sown, though it lay dormant for fifty years before the seedling appeared above the soil.

The last of the four great biologists of the seventeenth century was ANTONY VAN LEEUWENHOEK (1632–1723). He came of a good Dutch family resident in Delft, where his ancestors had been wealthy brewers. Being himself well off, he did not require to work for a living, and the only public post he held was that of a sort of sheriff's officer with few duties and a salary of 10*s*. a week. Leeuwenhoek had a mania for making and collecting microscopes—it is said he possessed no fewer than 247 of them! His publications were almost equally numerous, as many as 125 treatises

appearing in the *Proceedings* and *Transactions* of the Royal Society alone. His first important contribution to science was on the Protozoa, or animalculæ, as he termed them, which he discovered in rain water. In 1681 he identified Bacteria, and described their structure and movements in so far as it was possible with his primitive instruments. He also studied the circulation of the blood in the tail of the tadpole and the web of the frog's foot, and his description is a considerable improvement on that of Malpighi. To him also belongs the credit of discovering spermatozoa, which had never previously been seen. But perhaps his most interesting work was in connection with a subject that had always roused acute controversy, viz. the spontaneous origin of life. In 1668 Redi had disproved abiogenesis in so far as the origin of maggots was concerned, but the possibility of the spontaneous generation of organisms as small as those that Leeuwenhoek had revealed opened the discussion once more. After a long series of careful observations Leeuwenhoek decided against spontaneous generation, and pronounced in favour of biogenesis. The controversy went on, however, for nearly two hundred years afterwards, until the matter was finally set at rest by TYNDALL and PASTEUR, and the aphorism *Omne vivum ex vivo*—No life save from pre-existing life—was recognized as an even wider generalization than that attributed to Harvey.

The closing years of the seventeenth century saw the birth of a really great experimental physiologist in the person of STEPHEN HALES. His life was a particularly uneventful one and is soon told. He was born in 1677, and at the age of nineteen went to Cambridge to be trained for the ministry. At Cambridge he devoted himself to scientific as well as to literary and philosophical studies, and while there no doubt saw, and perhaps came under the influence of, Newton. In 1708 he was appointed perpetual curate of Teddington on the Thames, where he remained in comparative retirement for the rest of his long life. He died in 1761, and was buried beneath the flagstones of — own parish church. He appears to have been a kindly

sympathetic man, known for his constant "serenity and cheerfulness of mind." He took his pastoral duties very seriously, and showed great interest in the well-being of his parishioners, inaugurating a water-supply for the village and inventing a ventilating system for its public buildings, afterwards introduced into the London prisons. His fame as a scientific man rests, however, on his *Statical Essays*, consisting of two parts, entitled *Vegetable Staticks* and *Hæmostaticks*, the former published in 1727 and the latter in 1733.

In these treatises he showed himself to be a most capable experimenter, gifted with great ingenuity in devising apparatus for the solution of the physiological problems that engaged his attention, and with a mathematical and logical reasoning ability for working out results. In one respect he really anticipated Black in collecting, under a pneumatic trough, the gas given off from burning limestone. His biographer, the late Sir Francis Darwin, is probably correct in saying that he was "a chemist and physicist who turned his knowledge to the study of life, rather than a physiologist who had some chemical knowledge." He successfully demonstrated blood pressure in animals, inventing the manometer for that purpose, and measured the height of the pulse wave by the somewhat crude method of cutting an artery and allowing the blood to squirt out!

In the *Vegetable Staticks* he tackled the corresponding problem in plants, and was able to devise experiments the results of which led him to the conclusion that there did exist in plants a sap-pressure, subject to daily and thermal periodicity, but that the pressure was upwards only, from which fact he concluded that there was no such phenomenon as a circulation of sap comparable with the circulation of arterial and venous blood in the animal. He measured the amount of water given off in transpiration and the amount absorbed by the root, and, from the variations in these amounts during the day and night, estimated the rate of ascent of the transpiration stream. The cause of

ascent he ascribed to root pressure, capillarity and surface evaporation. He demonstrated transpiration to be the chief function of the stomata, and held that "plants very probably draw through their leaves some part of their nourishment from the air," a remarkably astute guess at what proved to be the fact, as shown by Ingen-Housz fifty years afterwards.

In the investigation of the problem of sexuality he was not so successful, for here he depended more on conjecture than on experiment, laying stress on the importance of air, sulphur and "particles of light" (Newton's corpuscular theory of light is obviously referred to) as being "by far the most active principles in nature" in bringing about "the invigoration of the seminal plant."

In spite of many misconceptions, inevitable in the case of one living before the composition of air was known, Hales may still be regarded as the founder of vegetable physiology, and he stands in the first rank among the biologists of all time.

Undoubtedly the most important chemical process in organic nature is that known to the modern botanist as photosynthesis—*i e* the ability of green plants to utilize the energy of sunlight in the construction of carbon compounds when supplied with the raw materials, carbon dioxide and water. The kinetic energy of sunlight, by the agency of green plants, becomes potential in the chemical products formed, again to become kinetic when released by oxidation "In this sense," as Sir J. Bretland Farmer truly says, "we are indeed all children of the sun, for its energy, reaching us through the mediation of the plant, is the *fons et origo* of our existence" Whether we acknowledge it or not, we are in truth all worshippers of Amon-Ra, the Sun god, "who giveth life"

Although, as we have seen, Grew identified chlorophyll, and even extracted it from the green leaf, he had no conception of its importance in the scheme of Nature, but after Black had discovered "carbonic acid," and Priestley had confirmed Mayow's discovery of oxygen, it became

possible to guess at the source of the plant's carbon, and to outline roughly the fundamental facts in this most important phase in plant nutrition. This was the task of a Dutch physician, JAN INGEN-HOUSZ, who was born at Breda in Holland in 1730, and who, after a period of service as physician to the Emperor of Austria at Vienna, settled in London, where, in leisure intervals of his professional labours among the gouty and dyspeptic attendants at the Court of George III., he carried out his *Experiments on Vegetables*. He showed experimentally that plants, if exposed to sunlight, obtained their carbon from the carbon dioxide of the air, and that they elaborated this substance in their leaves, retaining the carbon in the organic form and emitting the oxygen. Later, in 1796, he seems to have assimilated the teaching of the great chemist Lavoisier, and gave a more correct account of the phenomena, although he failed to appreciate the relation of photosynthesis to respiration, a relation which confused many physiologists after his day.

Important as were the additions to the knowledge of plant physiology made by Hales and by Ingen-Housz, they are equalled if not eclipsed by those of NICOLAS THÉODORE DE SAUSSURE. This distinguished chemist and physiologist was born in Geneva on October 14, 1767, the son of Horace Benedict de Saussure, the celebrated naturalist, Alpine explorer and professor in the university of Geneva. As a boy Théodore was trained under a private tutor and afterwards by his father, in preparation for entry into the academy of his native city. His studies embraced medicine, mineralogy and natural history, and he also acquired a keen interest in experimental chemistry from reading the earlier works of Lavoisier.

While still a lad, Théodore accompanied his father on his geological excursions, and learned from him habits of accurate observation of natural phenomena, an accomplishment rare indeed in those days.

In later years his chief labours lay in the field of plant nutrition opened up by the researches of Priestley and

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De Saussure's chief work was undoubtedly his *Recherches chimiques sur la Végétation*, published in 1804. This treatise is really a condensed account of several papers contributed separately to various journals from 1797 onwards. He showed experimentally that plants "exposed in atmospheric air to the successive action of day and night, inspire and expire oxygen mixed with carbonic acid gas," but that this phenomenon was not exhibited by non-green parts, for that they used oxygen for respiratory purposes only. He held that the plant obtained its carbon from the carbon dioxide of the air only, and that an increase of this gas in the air (up to 8 per cent) favoured nutrition, provided that light was correspondingly increased in intensity. He pointed out that the carbon dioxide produced during respiration in daylight was not given off, but was decomposed at once in the nutritive process, and hence that respiration *appeared* not to be taking place He also noted that both water and carbon dioxide were decomposed at the same time. He added very materially to our knowledge of the part played by minerals in plant nutrition, and showed that not only were these salts essential, but that they played a very important part in growth. The nitrogen came, he said, not from the air, where it was present in excess, but from the soil, but, unfortunately, he held that the source of this element was animal and plant waste, a doctrine known as the "humus theory," exploded by Liebig many years afterwards Finally, he drew attention to the extreme dilution of the salt solution taken in by the roots, although he did not correlate his observations with the related phenomena of transpiration His work was quite unique

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for the time at which it was written, since it was based on strictly scientific principles, and little of any value was added to the knowledge of plant nutrition for more than a generation afterwards.

Towards the close of the seventeenth century Malpighi and others had observed the periodic movements of the leaves of certain plants belonging to the Leguminosæ, the responses to contact made by those of the "sensitive plant," and the geotropic curvatures of roots and phototropic bendings of young shoots, but these observations were quite unco-ordinated. Later writers also studied these movements, but each and all ascribed them to physical causes or to a mysterious "vital force."

The first to investigate the problem experimentally was THOMAS ANDREW KNIGHT (1758–1838), a horticulturist of Hertfordshire. In the early years of the nineteenth century he announced his discovery of the persistent turning of the roots of seedlings towards the soil and of shoots away from it, no matter how he disposed the seedlings in the first instance. By fixing seedlings in varied orientation on a rapidly-rotating wheel, he discovered that, after an interval, all the roots turned outwards and all the plumules turned inwards. On causing the wheel to revolve in a horizontal plane, he found that the radicles pointed downwards and the plumules upwards at angles from the horizontal dependent on the rate of rotation of the wheel. This simple instrument, known as "Knight's wheel," was the forerunner of the modern klinostat. Knight advanced a purely mechanical explanation of these movements, viz. an alteration in the position of the sap. He also investigated the effect of moisture on roots, and found that they grew towards it, even in opposition to gravity, or, in other words, that they were hydrotropic. Heliotropic curvature was also studied, as well as the coiling of tendrils in response to contact, but in all cases he attributed the result to the transference of sap from one side of the organ concerned to the other. The diaheliotropic performances of dorsiventral leaves perplexed him exceedingly, and he ended by

JOHN RAY, 1628-1705
(From the painting by Mrs. Beale (?) in the National Portrait Gallery.)

saying, "I am wholly unable to trace the existence of anything like sensation or intellect in plants," although he confessed that the leaf movements could not be accounted for "without admitting not only that the leaf possesses an

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saying, "I am wholly unable to trace the existence of anything like sensation or intellect in plants," although he confessed that the leaf movements could not be accounted for "without admitting not only that the leaf possesses an

ntrinsic power of moving, but that it also possesses some vehicle of irritation." A correct explanation could not, of course, be put forward until protoplasm, with all its mysterious properties, had been discovered; but this was not until some forty years had elapsed.

During the long years that had passed since the times of the Herbalists many attempts had been made to formulate a classification of the ever-increasing multitude of plants that were being brought from all parts of the world by travellers, and the task of the systematist was becoming more strenuous and perplexing day by day. The English botanist JOHN RAY (1628–1705) wrote a work called the *Historia Plantarum Generalis*, which earned for him the title of being "the greatest European botanist of the seventeenth century," while on the Continent several alternative systems were published; but all these efforts were eclipsed by the work of Carl von Linné, or LINNÆUS, as he is more usually named.

Linnæus was born at Rashult in Sweden in 1707, the son of the village pastor. At school the boy showed no aptitude for learning as it was then understood, and his disappointed father proposed to apprentice him to a cobbler. He was saved from this degradation by the efforts of a local doctor, who recognized the boy's interest in natural history and induced his father to allow him to study medicine at the university of Lund. From Lund h went to Upsala, where he ultimately acted as locum tene for the aged professor of botany, Rudbeck. In 1732 went to Lapland on an exploring expedition on behalf the Academy of Sciences of Upsala, and thus lived up his family motto, *Famam extendere factis*. On his ret he supported himself by public lecturing and private tuit He next fell in love with the daughter of a wealthy physic but the prospective father-in-law would consent to th trothal only on condition that Linnæus took a me degree and settled down to practise. The young lady was devoted to her naturalist lover, aided him finan

LINNÆUS, 1707–78.
(From an engraving after the portrait in the possession of the Royal Society at Stockholm.)

and, with her money and his own, he went to Holland, where he graduated in 1735. On the recommendation of the chemist, Boerhaave, Linnæus was appointed physician to the burgomaster of Amsterdam, who was himself an en-

siastic botanist. After three and a half years' absence, ing which he visited London and Paris, he returned to eden and married the lady of his choice, who had so nerously aided him in his earlier struggles. In 1741 he as appointed professor in the university of Upsala, and as thus at last in a position to devote himself entirely the pursuits in which he became so famous.

Linnæus was a voluminous writer, the *Systema Naturæ* (1735), *Fundamenta Botanica* (1736), *Genera Plantarum* (1737), *Classes Plantarum* (1738), and the *Philosophia Botanica* (1751) being among the best known of his works.

" The chief services of Linnæus to natural science consisted of three things: bringing into current use the binomial nomenclature, the introduction of terse formulæ for description, and fixing attention upon species. The first two were necessary steps; they introduced clearness and order into the management of the immense number of details, and they made it possible for the observations and discoveries of others to be understood and to take their place in the great system of which he was the originator. The effect of the last step was to direct the attention of naturalists to species, and thereby to pave the way for the coming consideration of their origin, a consideration which became such a burning question in the last half of the nineteenth century. . . . However much we may admire the industry and force of Linnæus, we must admit that he gave to natural history a one-sided development, in which the more essential parts of the science received scant recognition. His students, like their master, were mainly collectors and classifiers. In their zeal for naming and classifying, the higher goal of investigation—knowledge of the nature of animals and plants—was lost sight of, and the interest in anatomy, physiology, and embryology lagged." (Locy.) The great anatomist and zoologist, Hertwig, sai of him: " For while he in his *Systema Naturæ* treated of a extraordinarily larger number of animals than any earli naturalist, he brought about no deepening of our kno ledge. . . . Zoology would have been in danger of grow

into a Tower of Babel of species description if a counterpoise had not been created in the strengthening of the physiologico-anatomical method of consideration."

It has been well pointed out by Locy that since "the chief aim of biological study is to extend our knowledge of the structure, development, and physiology of animals and plants as a means of understanding more about their life, the arrangement of animals and plants into groups should be the outcome of such studies rather than an end in itself." Linnæus's system was essentially artificial, a useful directory, but giving no conception of relationships. His so called "sexual system"—the title even is a misnomer—retarded progress in natural classification for more than half a century, but this was due not so much to Linnæus himself, who regarded his scheme as only provisional, as to the unreasoning adherence to his classification of his enthusiastic but far from critical followers. The *Systema* had its day and passed, replaced by the more natural schemes of De Jussieu and De Candolle in botany, and of Lamarck and Cuvier in zoology

Before we consider the final scenes in the drama of biological evolution we must glance at one development of fundamental importance in the science, viz. the discovery of what Huxley long afterwards called "the physical basis of life" As early as 1665 Hooke, it may be remembered, applied the term "cells" to the microscopic cavities his lenses had disclosed in the slices of animal and vegetable tissues he had examined After the Scottish botanist ROBERT BROWN (1773 1858) had discovered the presence of a nucleus in the vegetable cell, attention became more centred on the contents of these cavities than on the structure of the walls that bounded them, with the result that these contents were found to be nitrogenous in their chemical nature Similarly, in the animal world the cell contents were also recognized as composed of nitrogenous compounds, and were called "sarcode," or flesh, by DUJARDIN (1801–60) The next step was taken by the

botanist VON MOHL (1805–72), who in 1844 announced that the "slime" in the plant cell and the "viscid granular substance" of the animal cell were one and the same substance, and that both were living. To this substance he gave the name "protoplasm." Here at last was the "vehicle of irritation" dimly hinted at by Knight, the real seat of the "vital force" believed in so firmly by the physiologists of the closing years of the eighteenth century. The essential unity of the plant and the animal as bionts or *living* things, thus became established by the recognition of the existence of a common structural basis whose activities expressed themselves on one side in plant life and on the other in animal life, culminating in one direction in a forest tree, and in the other in man himself.

CHAPTER X

THE INTERPRETERS OF LIFE

THE world, as every one knows, is peopled by living organisms of two kinds, plants and animals, and botanists and zoologists alike agree in recognizing that there is a gradation in structure and complexity from the lowliest plant or animal that lives as a unicellular organism—like the bacterium and the protozoon that Leeuwenhoek discovered on his toothbrush and in the puddle at his doorstep, or the green slime that Priestley's friend saw in the inn-keeper's horse-trough at Harwich—right up to the elaborate flowering plant and forest tree, or the herbivorous or carnivorous mammal that roams over the prairie or haunts the forest glade

Moreover, from the earliest times it was observed that these organisms, plant or animal, seemed to segregate themselves into groups—seaweeds, fungi, ferns, or flowering plants on the one hand, or worms, crustaceans, fish, reptiles, birds, or mammals on the other Further still, as men became more discriminating in their observation, it was seen that, under these larger groupings, there were ever finer and finer subdivisions, in the limitation and ordering of which the biologists of long ago exercised their ingenuity with more or less success What eventuated at length was the recognition of a hazy abstraction called a " species " It was easy enough to say that all the wild dog roses belonged to one species, *Rosa canina*, or all the frogs to one species, *Rana temporaria*, but if one inquired what a species was no clear and definite answer was forthcoming Some said that species were groups of individuals agreeing in

essential characters which remained constant from generation to generation. But what were essential characters, and how much constancy could be demonstrated? Linnæus held that "there are just so many species as in the beginning the Infinite Being created." Perhaps—but who was to enumerate these and what was the date of the beginning? To take one example only from our British flora, Bentham, our leading systematist, gives us 7 species of the genus Hieracium or hawkweed; Hooker, another great authority, gives us 9; but Druce of Cambridge, working, be it noted, on the *same* material, gives us no less than 134, while the authoritative *London Catalogue of British Plants* enumerates 247! Truly among the multitude of counsellors there is not wisdom, but confusion!

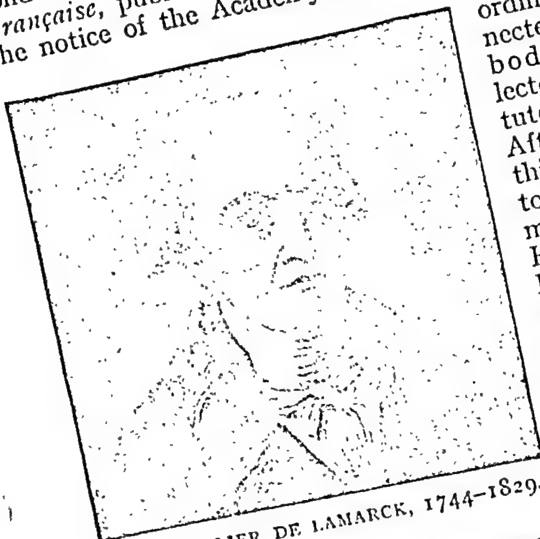
The fact is there is no such thing as species. Individuals are real enough, but a species is a purely subjective conception, of which it may be truly said, *quot homines, tot sententiæ*. It is based on structural resemblances between individuals, and the degree of importance attached to these depends entirely on the mind of the observer. Hence we arrive at two possible interpretations of the relationships of living things: either each species—however the term may be actually defined—was "specially created," or that species flow into each other so gradually that the only possible explanation is that they are all phylogenetically related. If the first view be accepted, the onus lies on those who are ready to give such a definition of a species as will be acceptable to all, and are prepared also to substantiate the doctrine of the special creation of such entities in the Garden of Eden, or in any other region or regions of the earth; but if this view be rejected in favour of the obviously more rational one, that species have been evolved from pre-existing species, then some reasonable hypothesis must be put forward to account for such evolutionary progress. Here again we meet with difficulties, for the question at once arises what were the factors that operated in the past in inducing such changes in species? What are their relative values, and are they still operative and to what

extent? The American zoologist Packard gives us at least a starting-point when he writes, "We are all evolutionists, though we may differ as to the nature of the efficient causes."

Looking backwards, we naturally associate the evolu-
amarck,
the last
tempt to
gain some conception of the contributions of each of these five men to the doctrine of organic evolution, a doctrine which, as one of them (Weismann) said, was "the most progressive step that has been taken in the development of human knowledge . . . The conception of an evolution of life upon the earth reaches far beyond the bounds of any single science, and influences our whole realm of thought. It means nothing less than the elimination of the miraculous from our knowledge of nature, and the placing of the phenomena of life in the same plane as the other natural processes—that is, as having been brought about by the same forces and being subject to the same laws."

LAMARCK was born at Bazentin in Picardy in 1744, and, unlike his elder brothers, who adopted the military profession, he was destined for the Church. In consequence of this decision he became a pupil in the Jesuits' College at Amiens, where, however, he developed a pronounced distaste for theological studies, and took the first opportunity, after his father's death in 1760, of absconding and joining the French army, then engaged in the Seven Years' War. Against his commanding officer's wishes he persisted in serving, and, as he arrived mounted on a derelict quadruped which he had purchased somehow, he was made a non-commissioned officer. His company suffered so severely in his first battle that Lamarck found himself, a lad of seventeen, in command of all that was left of it. But here he showed that courage and determination that distinguished him throughout his whole career, for he resolutely refused to retire in the face of great odds until he had received orders from headquarters to do so. Invalided

om the army owing to an accident, he went to Paris to tudy medicine, but from the beginning showed himself particularly attracted to botany. The fruit of five years' unremitting labour, carried out under poverty-stricken conditions and without any encouragement, was his *Flore Française*, published in 1778. This work brought him to the notice of the Academy of Sciences, and after a short tenure of a subordinate post connected with that body, he was selected by Buffon as tutor to his sons. After two years of this life he returned to Paris, and was made keeper of the Herbarium of the Royal Gardens, and finally professor in the re-named Jardin des Plantes. In 1794 Lamarck transferred his affections from botany to zoology and immediatel proceeded to reor



THE CHEVALIER DE LAMARCK, 1744–1829.

ganize the classification of the lower animals, which up ti then had received the minimum of attention from zoologist He published his results between 1815 and 1822 in splendid work *Histoire naturelle des Animaux sans Vertèbr* Meanwhile he had become totally blind, and might h collapsed altogether had it not been for the courage devotion of his daughter, Cornélie, who was his cons helper and sympathizer where the outside world tre him with indifference. Her prediction as to her fa future greatness came true in later years—"la pos vous honerera." Lamarck died in 1829.

We need not do more than refer to his views on the origin of life, for they were tinctured with an undoubted bias towards a belief in spontaneous generation; we may rather turn to his theory of evolution, which, although vigorously combated and even ridiculed, was the first serious attempt to overthrow the dogmas of special creation and of the constancy of species.

... tion is given in

(1) Life, by its prop... increase the volume of every body possessing it, and to enlarge its parts, up to a limit which it brings about.

(2) "The production of a new organ in an animal body results from the supervention of a new want continuing to make itself felt, and a new movement which this want gives birth to and encourages.

(3) "The development of organs and their force of action ... of these organs. ... down, or changed ... course of their life is conserved by generation and transmitted to the new individuals which proceed from those which have undergone those changes."

Put very briefly and in more familiar terminology, Lamarck's explanation was that variation is explicable on the ground of use and disuse; the constant use of an organ tends to its development. At a later date a certain witty Scottish judge, called Lord Neaves, wrote a jingle purporting to be a sarcastic attack on the Darwinian theory, but, in his ignorance, he humorously ridiculed Lamarck's hypothesis:

> ... which was longer by half

Lamarck's fourth proposition announces his belief in what has come to be called "the inheritance of acquired

characters," viz. that every alteration in the structure of an organism arising from use or disuse, or resulting from the influence of environment or external stimulus, is passed on to its offspring, either to be maintained by it or to fall into abeyance and ultimately abort. Lamarck accepted the obvious corollary that an immense period of time and favourable conditions would be required to produce new species. When these conditions remained stable he assumed that the organism, being adapted to them, would also remain stable.

Whatever else may be said for or against Lamarck's theory, we must give him the credit of recognizing the two fundamental factors that every evolutionist must take cognizance of, however he may account for them, viz. the phenomena of variation and the phenomena of heredity.

The year 1859 was destined to be a fateful one, not merely for biology, but for every department of learning, for in that year was published a book that has had a deeper and more wide-reaching influence on the trend of human thought and endeavour than any other that has ever come from the printer. That book was *The Origin of Species*, by Charles Darwin. [The following paragraphs, within single inverted commas, are quoted from the author's *Outlines of the History of Botany*.]

'CHARLES DARWIN was born in 1809 at Shrewsbury, where his father was a well-known medical man. His mother was a daughter of the founder of the famous Wedgwood Potteries (who was also a friend of Priestley). It is rather amusing to read how Darwin's early teachers looked upon him as not far removed from a dunce. These were the days when higher education was considered as synonymous with an intimate knowledge of the classics, and it is on record that his headmaster publicly reprimanded Darwin for "wasting his time on such a contemptible subject as chemistry." *Omnia mutantur nos et mutamur in illis*, and the narrow-minded classicist who regards Latin and Greek as the one and only basis of a liberal education is rapidly

succumbing to the fate that has overtaken the Lepidodendron and the Ichthyosaurus. "The school as a means of education to me was simply a blank," Darwin himself writes, and Huxley adds, "As a matter of fact Darwin's school education left him ignorant of almost all the things which it would have been well for him to know, and untrained in all things it would have been useful for him to be able to do in after life. Drawing, practice in English composition, and instruction in the elements of the physical sciences would not only have been infinitely valuable to him in reference to his future career, but would have furnished the discipline suited to his faculties, whatever that career might be."

'Darwin does not appear to have been much more of a success at college than he was at school. At Edinburgh, where he went to study medicine, he found the professors "intolerably dull," and says that the lectures of the professor of materia medica were "fearful to remember," while he describes the discourses of the professor of anatomy as having been "as dull as he was himself." As Huxley puts it, "The climax seems to have been attained by the professor of geology and zoology, whose prælections were so incredibly dull that they produced in their hearer the somewhat rash determination never to read a book on geology or in any way to study the science so long as he lived."

'Finding himself not likely to become a successful medical man, Darwin exchanged Edinburgh for Cambridge, where he entered Christ's College with the view of reading for holy orders, but he had no better words to say for Cambridge than he had for Modern Athens. "During the three years which I spent at Cambridge," he says, "my time was wasted, as far as academic studies were concerned, as completely as at Edinburgh and as at school." If he passed the door of the geology lecture room with a cold shudder, he found his way into the botanical one and there he made the acquaintance of Henslow, "a man of rare character and singularly extensive acquirement in all

branches of natural history." The acquaintance grew into friendship which lasted till Henslow's death in 1861. Henslow overcame Darwin's prejudice against geology, and succeeded in introducing him to Sedgwick, at that time professor of geology at Cambridge, and Darwin had to forswear his vow never to study the science, for he not only accompanied the professor on his geological excursions, but set himself to master Lyell's *Principles of Geology*, a work to which in after years he professed himself as fundamentally indebted.

'Henslow is, however, responsible for more than merely turning Darwin's thoughts to botany and geology; he showed himself possessed of a far-seeing vision that was the means of dedicating to science the man who was destined to become perhaps the greatest of her high-priests. For it was due to Henslow that Darwin, when scarcely out of his teens, was appointed naturalist on the *Beagle* for a five years' surveying voyage round the world. "So," again to quote Huxley, "a fourth educational experiment was to be tried; this time Nature took him in hand herself," and where the Shrewsbury pedagogue, the Edinburgh medicos and the Cambridge theologians had signally failed, Nature showed him the way by which, to borrow Henslow's prophetic phrase, "anything he pleased might be done."

'This fourth educational experiment was as successful as the others had been fruitless, and was, as Darwin himself puts it, the starting-point of his second life.

'"When I was on board the *Beagle*," he writes, "I believed in the permanence of species, but, as far as I can remember, vague doubts occasionally flitted across my mind. On my return home in the autumn of 1837 I immediately began to prepare my journal for publication, and then saw how many facts indicated the common descent of species, so that in July 1837 I opened a notebook to record any facts which might bear on the question. But I did not become convinced that species were mutable until, I think, two or three years had elapsed."

'Soon after his return from his travels Darwin came

across a famous book called *An Essay on the Principles of Population*, written by the Rev. Thomas Malthus, a Surrey vicar, who had died while Darwin was abroad. The essay was a very pessimistic production, aimed at controverting the rhapsodic views of the Rousseau school of thinkers. Malthus argued that organisms, if left perfect freedom to breed and given unlimited room in which to multiply, would fill any conceivable area in a very short time. The only limits to their increase were those of space and food. So far as man was concerned propagation was controlled by reason, although, in his case also, the same limitations were existent and active, and these he proceeded to enumerate and illustrate from the histories of different nations.

'Darwin wrote out his theory in 1844, but, instead of publishing it at once, he spent the next fifteen years gathering new data bearing on the various aspects of the subject, conducting experiments and, so to speak, polishing the rough-hewn marble into the perfect statue. During this period also he was busily engaged in working out other problems suggested by or connected with his main thesis, the gist of which latter was known only to a few intimate friends. At length in 1856, at Lyell's instigation, Darwin began to expand the preliminary sketch of his theory that he had written twelve years before so as to bring it into book form, but with no immediate intention of publishing.

'Then there descended a bolt from the blue. ALFRED RUSSEL WALLACE, a young architect, who had for some years exchanged his practice for a life of travel and exploration in Brazil and Malaya, and with whom Darwin had had considerable correspondence on natural history subjects, sent him an essay on *The Tendency of Varieties to depart indefinitely from the Original Type*, the outcome of his observations and meditations amid the tropical forests of the eastern archipelago, and which, as Darwin says, was, in effect, an admirable abstract of his own unpublished book. After consultation with his two most intimate friends, Lyell and Hooker, he decided to publish Wallace's essay and an abstract of his own work simultaneously, and the

two papers were read to the Linnean Society on July 1, 1858, a truly historic date and one to be remembered by every student of biology.

'A little over a year thereafter appeared the famous volume, *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life.*

'Huxley's résumé of the work is as follows: "Observation proves the existence among all living beings of phenomena of three kinds, denoted by the terms heredity, variation, and multiplication. Progeny tend to resemble their parents; nevertheless all their organs and functions are susceptible of departing more or less from the average parental character; and their number is in excess of that of their parents. Severe competition for the means of living, or the struggle for existence, is a necessary consequence of unlimited multiplication; while selection, or the preservation of favourable variations and the extinction of others, is a necessary consequence of severe competition 'Favourable variations' are those which are better adapted to surrounding conditions. It follows, therefore, that every variety which is selected into a species is so favoured and preserved in consequence of being, in some one or more respects, better adapted to its surroundings than its rivals. In other words, every species which exists, exists in virtue of adaptation, and whatever accounts for that adaptation accounts for the existence of species."

'"It is doubtful," writes Huxley, "if any single book, except the *Principia* [of Isaac Newton] ever worked so great and so rapid an evolution in science, or made so deep an impression on the general mind. It aroused a tempest of opposition and met with equally vehement support, and it must be added that no book had been so widely and persistently misunderstood by both friends and foes."

'During his voyage in the *Beagle* Darwin suffered much from the effects of a serious illness contracted at Valparaiso, and this left its mark upon him to such an extent that, as

ALFRED RUSSEL WALLACE, 1823–1913.

he tells us in his autobiography, he never really recove[illegible] his initial health and strength. "My chief enjoyment [illegible] sole employment throughout life," he writes, "has be[illegible] scientific work, and the excitement from such work ma[illegible] me, for the time, forget or drives quite away, my [illegible] discomfort. I have, therefore, nothing to record du[illegible] the rest of my life, except the pub[illegible]cation of my se[illegible] books." After 1842 Darwin removed from Lond[illegible]

country residence at Down in Kent, where he spent the remainder of his years.'

It is unnecessary to refer to the very numerous publications on almost every branch of natural history to which Darwin refers in the sentences just quoted; any one of them would have earned him distinction, had they not been overshadowed by the great classic that has rendered his name immortal.

'In the beginning of 1882 Darwin's health, always feeble, began to give way very rapidly, and he breathed his last on April 19 of that year, at the age of seventy-three.'

It had been the wish of his family that he should be buried at Down, but they bowed to the widespread feeling that a man so illustrious should find his last resting-place in the national Valhalla; so on April 26 his funeral took place in Westminster Abbey, attended by representatives of all the great nations, as well as by very many distinguished personages and personal friends. Appropriately enough, he lies only a few feet from his only compeer, Sir Isaac Newton, and his tomb bears the inscription he would have regarded as most fitting in its simplicity:

CHARLES ROBERT DARWIN
Born 12 February, 1809.
Died 19 April, 1882.

The closing sentences of Huxley's noble panegyric which appeared a week after his death, may form an appropriate conclusion to the life-story of this great man.

"It is not for us to allude to the sacred sorrows of the bereaved home at Down; but it is no secret that, outside that domestic group, there are many to whom Mr. Darwin's death is a wholly irreparable loss And this not merely because of his wonderfully genial, simple, and generous nature; his cheerful and animated conversation, and the infinite variety and accuracy of his information; but because the more one knew of him, the more he seemed the incorporated ideal of a man of science. Acute as were his

[illegible]

CHARLES DARWIN

[illegible]

reasoning powers, vast as was his knowledge, marvellous as was his tenacious industry, under physical difficulties which would have converted nine men out of ten into aimless invalids; it was not these qualities, great as they were, which impressed those who were admitted to his intimacy, with involuntary veneration, but a certain intense and almost passionate honesty by which all his thoughts and actions were irradiated, as by a central fire.

"It was this rarest and greatest of endowments which kept his vivid imagination and great speculative powers within due bounds, which compelled him to undertake the prodigious labours of original investigation and of reading, upon which his published works are based; which made him accept criticisms and suggestions from anybody and everybody, not only without impatience, but with expressions of gratitude sometimes almost comically in excess of their value, which led him to allow neither himself nor others to be deceived by phrases, and to spare neither time nor pains in order to obtain clear and distinct ideas upon every topic with which he occupied himself.

"One could not converse with Darwin without being reminded of Socrates. There was the same desire to find some one wiser than himself, the same belief in the sovereignty of reason, the same ready humour, the same sympathetic interest in all the ways and works of men. But instead of turning away from the problems of Nature as hopelessly insoluble, our modern philosopher devoted his whole life to attacking them in the spirit of Heraclitus and of Democritus, with results which are the substance of which their speculations were anticipatory shadows.

"None have fought better, and none have been more fortunate than Charles Darwin. He found a great truth trodden under foot, reviled by bigots, and ridiculed by all the world, he lived long enough to see it, chiefly by his own efforts, irrefragably established in science, inseparably incorporated with the common thoughts of men, and only hated and feared by those who would revile, but dare not. What shall a man desire more than this? Once more the

image of Socrates rises unbidden, and the noble peroration of the 'Apology' rings in our ears as if it were Charles Darwin's farewell:

> *The hour of departure has arrived, and we go our ways—*
> *I to die and you to live. Which is the better, God only knows."*

"The lapse of time, with the truer proportions that distant vision gives," writes Professor Graham Kerr of Glasgow University, "will show the figure of Charles Darwin towering alone above all others in the history of Philosophy."

Although it is not the purpose of this book to carry the subject of the development of science beyond the middle of last century, a word or two may be added in the present relation on the views of some of the followers of Darwin.

WEISMANN (1834–1914), who was a strong supporter of Darwin's theory, broke away from it in one respect, viz. as to the inheritance by the offspring of characters acquired by the parent during its lifetime. He held that a certain part of the fertilized ovum is, so to speak, put on one side from the very commencement of the developmental process to serve as a starting-point for the germ cells of the new organism, and to this hypothetical substance he gave the name of "germ-plasm," the remainder being known as "somato-plasm." If, as Weismann thought, germ-plasm and somato-plasm were initially distinct, and if the germ-plasm was alone concerned in the transmission of characters, it was obvious that modifications of the somato-plasm could not be transmitted, that any structural change in a part of the body induced by use or disuse, or by environmental or nutritive influences generally, never affected the germ-plasm in such a way as to cause the offspring to exhibit the modification that the parent had acquired, or even to show a tendency in that direction.

Among the difficulties that weighed largely with Darwinian evolutionists was the prodigious time that must be allowed for the operation of natural selection, and, further, the question arose—why were not intermediates of all sorts

more abundant in nature than was actually known to be the case? Such criticisms seemed to be met to some extent by De Vries, professor in Amsterdam, who, in 1901, published an important work on what he termed *Mutations*.

GREGOR MENDEL, ABBOT OF BRÜNN

From a long study of Œnothera, the Evening Primrose, he came to the conclusion that new varieties might spring into being at a bound, so to speak, and his work raised the suspicion that variation might be discontinuous and not due to the slow accumulation of infinitesimal additions.

The whole aspect of the problem of inheritance of char

s was altered, however, by the discovery of a paper, ten in 1865, just after the publication of the *Origin of cies*, by GREGOR JOHANN MENDEL, an Austrian monk, o was abbot of the monastery of Brünn in Moravia. angely enough Mendel makes no reference to Darwin, d "it is remarkable that, as far as we know, Darwin ver in any way came across Mendel's work." If that ad been the case, perhaps, as Bateson says, "the history f the evolutionary philosophy would have been very dif-erent from that which we have witnessed."

Mendel's paper was printed in the *Journal* of the Brünn Society of Natural History, and lay hidden there for over thirty-five years, but when it was unearthed by De Vries and others in 1900 it immediately attracted the attention of the whole biological world. The name of the almost unknown abbot (who died in 1884) is now one of the most prominent in the whole range of biology. The Mendelian hypothesis, founded on a long series of experiments on breeding carried out in the monastery garden, has been ably expounded by Professor Punnett of the university of Cambridge, and a quotation from his work on the subject will show at once what a new and startling light Mendel threw on the whole problem of evolution.

According to the Mendelian hypothesis "heritable variation has a definite basis in the gamete (ovum or sperm), and it is to the gamete, therefore, not to the individual, that we must look for the initiation of the process. Somewhere or other in the course of their production is added or removed the factor upon whose removal or addition the new variation owes its existence. The new variation springs into being by a sudden step, not by a process of gradual and almost imperceptible augmentation. It is not continuous, but discontinuous, because it is based upon the presence or absence of some definite factor or factors—upon discontinuity in the gametes from which it sprang. Onc formed, its continued existence is subject to the arbitramen of natural selection. If of value in the struggle for existenc natural selection will decide that those who possess it sha

have a better chance of survival and of having offspring than those who do not possess it. If it is harmful to the individual, natural selection will soon bring about its elimination. But if the new variation is neither harmful nor useful there seems no reason why it should not persist. On the old view, no new character could be developed except by the piling up of minute variations through the action of natural selection. Consequently any new character found in animals or plants must be supposed to be of some definite use to the individual, otherwise it could not have developed through the action of natural selection. But there are plenty of characters to which it is exceedingly difficult to ascribe any utility, and the ingenuity of the supporters of this view has often been severely taxed to account for their existence. On the more modern view this difficulty is avoided. The origin of a new variation is independent of natural selection, and provided that it is not directly harmful, there is no reason why it should not persist. In this way we are released from the burden of discovering a utilitarian motive behind all the multitudinous characters of living organisms. For we now recognize that the function of natural selection is selection and not creation. It has nothing to do with the formation of the new variation. It merely decides whether it is to survive or to be eliminated."

On Mendel's principles has arisen, in our own times, a new branch of biology called Eugenics, and its priests would have us lay down laws to supersede even those that Nature has established. Perhaps they may be right, but will the laws be obeyed even when they are made?

Our glimpses into the past history of science now come to an end, leaving its present and its future unspoken of. In the eighteenth century the seeds of our modern knowledge of nature were sown, but it was not until the nineteenth century that the first harvest was garnered, while from its seed in turn developed the wondrous crop that has matured in our own time.

What the future may hold in store no one can prophesy with any certainty, although confident anticipation runs high. Many of the secrets of the heavens and of the earth have been revealed, but these are only the preliminary glimpses of a knowledge of the ocean of truth yet to be acquired.

> "Men, my brothers, men the workers, ever reaping something new;
> That which they have done but earnest of the things that they shall do."

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